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Electrical Power Transmission Lines and Networks

By

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ELECTRICAL POWER TRANSMISSION LINES AND NETWORKS

Moscow PROBLEMY RAZVITIYA ENERGETIKI in Russian 1978 pp 2, 215-287

[Annotation, chapters 6 and 7, bibliography and table of contents from the book by D.G. Zhimerin, Energiya Publishers, 1978, 287 pages, UDC 620.9]

[Text] Scientific, engineering and economic problems of the development of power engineering are treated in the book: the trend in the development of the electrification of the national economy, the development of thermal electric power stations, the utilization of hydroelectric power resources, problems with the development of nuclear power engineering, the engineering prospects for the utilization of other energy sources as well as problems of environmental protection in power engineering construction.

The book is intended for a wide circle of power engineers, and can also be useful to instructors and students in the special engineering higher educational institutes.

Chapter 6 Electrical Networks

6.1. Electrical Power Transmission Engineering

A provision is made in the Main Trends for the Development of the National Economy during 1975-1980, adopted by the 25th CPSU Congress for the construction of "trunk electrical power transmission lines at voltages of 500, 750 and 1,150 kilovolts"* as one of the major tasks.

Considerable attention has always been devoted to the development and refinement of electrical power transmission engineering in our country.

The GOELRO [State Commission for the Electrification of Russia] plan provided for the construction of regional electric power stations, which were to provide

*Materials of the 25th CPSU Congress, Moscow, Politizdat, 1976, p 177.

the centralized electrical power supply for all of the enterprises of a given economic region. Thus, centralized electrical power supply governed the necessity of designing trunk and distribution electrical networks for various voltage levels.

The successes which were achieved in the design and continuous improvement of electrical power transmission lines and electrical networks in the USSR are the result of a centralized planning system. The project planning institutes of the USSR Ministry of Energy: Teploelektroproyekt, Energoset'proyekt and Gidroproyekt realize a uniform engineering policy in the development and refinement of electrical power transmission equipment, and in increasing its economic efficiency.

A uniform scale of voltages of 3, 6, 10, 35 and 110 KV for the entire nation was adopted in 1920 for the purpose of standardizing the alternating current electrical power transmission voltages, in place of the lower, uncoordinated voltages which were used earlier (2, 15 and 20 KV). Later, the scale of voltages was supplemented with higher gradients of 150 (temporarily), 220, 330, 400, 500, 750 and 1,150 KV. The authorization of the standard scale of voltages made it possible to standardize the production of power and instrumentation transformers, switches, disconnectors and other electrical equipment.

The organization of the production of electrical power equipment which was standardized in terms of the voltage and scale of capacities made it possible to obtain a greater economic impact. The operation of electrical power networks and power systems came to function with mutually interchangeable equipment, something which significantly reduced the expenditures for repair operations, as well as the replacement of obsolete or failed equipment.

The scientific principles for the expansion of electrical networks can be formulated as follows:

--The combining of electric power stations into common power systems is the basis for electrification;

--The parameters of electrical power transmission lines (voltage, carrying capacity, length) should increase in step with the development of electrical power engineering and the rise in generating capacities;

--In expanding electrical networks, it is essential to maintain strict conformity both to the growth in the overall generating capacity and also to take into account the electrification of all inhabited territory;

--In the expansion of the voltage of electrical power transmission lines, it is necessary to observe the proportions between through transit type lines and distribution lines, making a timely transition from through transit type lines to distribution lines in accordance with the expansion of the sphere of electrification;

--It is essential to strictly observe the proportions in the development of transformer capacities, generating sources and distribution substations;

--With an adequate level of expansion of the forces of production and power engineering management, it is necessary to change over to high power, ultra-long range electrical power transmission having a high economic efficiency.

Table 6.1

The Centralization of Electrical Power Generation

Годы Years	Производство электроэнергии, млрд. кВт·ч (1)		(3) Коэффициент централизации производства электроэнергии, %
	всего Overall	(2) в том числе на электростанциях общего пользования и блок-станциях	
1913	2,0	0,4	21,1
1928	5,0	1,9	38,9
1932	13,5	9,1	67,4
1940	48,6	39,2	81,2
1955	170,0	140,0	82,4
1965	507,0	470,0	92,8
1970	741,0	712,0	96,0
1975	1038,0	1008,0	97,0
1976	1111,0	1078,8	97,1

Key: 1. Electrical power generation, billions of KWH;
2. Including that of general service electric power stations and block stations;
3. The centralization coefficient of electrical power generation, percent.

As a result of the consistent development of electrical power engineering, the concentration of generating sources and construction of electrical networks, the centralization of electrical power generation has increased, something which can be seen from Table 6.1.

The voltage and configuration of electrical networks is governed to a well known degree by the structure of the power system. In the process of creating and accumulating operational experience with power systems, a selection is made of the most efficient configuration of electrical networks, which meet the basic requirements for power system organization and reliability in the supply of electrical power to consumers.

For a deeper understanding of the evolution of the development of electrical networks and electrical power transmission lines, it is necessary to briefly deal with the question of how the power systems were formed.

Two types of power systems were set up, taking into account the territorial arrangement of the consumers: ring and spatial systems. Electrical power systems are also differentiated with respect to the power flow distribution. Here, one can point out "centripetal" and "centrifugal" systems, in which the power flows are directed from the generating sources either towards the center or the periphery. The most reliable system is a ring system in which a backup is provided for the electrical power supply to the consumers.

Table 6.2

The Length of Open Wire Electrical Power Transmission Lines

Напряжение, кВ Voltage	(1) Протяженность линий электропередачи, тыс. км				
	1960 г.	1965 г.	1970 г.	1975 г.	1976 г.
35—800	124,4	306,8	445,5	604,8	638,4
0,5—22	25,0	659,5	1168,5	1454,2	1505,4
0,5 и ниже & less	69,5	815,1	1597,7	1762,2	1776,4
Всего Total	218,9	1781,4	3211,7	3821,2	3920,3

Key: 1. The length of electrical power transmission lines, thousands of km.

Table 6.3

The Dynamics of the Changes in the Specific Length of Electrical Power Transmission Lines

Напряжение, кВ Voltage, KV	(1) Удельная длина линий электропередачи, км/МВт					
	1928 г.	1940 г.	1950 г.	1960 г.	1970 г.	1975 г.
35—750	1,06	2,02	1,67	1,83	2,70	2,77
Including В том числе:						
35	0,26	0,72	0,61	0,55	1,06	1,10
110	0,50	0,94	0,84	0,97	1,12	1,12
220	—	—	0,13	0,23	0,31	0,32

Key: 1. The specific length of electrical power transmission lines, km/MW.

A ring configuration of an electrical power network is clearly visible in the example of the largest power system, the Moscow power system. A ring made of 110 KV lines was formed for the first time in this power system; with an increase in the capacity in the power system in 1940, 220 KV lines appeared, which then formed a second ring of the system (with a greater diameter).

When the Volga GES's [hydroelectric power stations] were brought on line, electrical power transmission lines at 500 KV were constructed from them to the Moscow power system. The two first rings at this time were no longer able to provide for sufficiently reliable electrical power supplies under normal conditions, and especially in emergency situations. The reliability of the electrical power supply of the most important Moscow economic region rose following the creation of the third, higher capacity ring, which was formed by 500 KV electrical power transmission lines.

The principle of closed rings made of power transmission lines at different voltages can also be used in other types of power systems. A typical example of such a power system is the combined Urals power system, which extends from the north to the south over a distance of more than 1,000 km. A local electrical power ring is formed inside the spatial Urals power system, in its central part.

Reliability of the electrical power supply to consumers in spatial systems is achieved by feeding the electrical power from double transmission lines, which run from the generating sources to the consumer. In this case, as a rule, the feed lines should transmit the power from the various generating sources.

Comprehensive electrification of the nation is accomplished through the solution of two major problems: encompassing all inhabited territory with power systems and achieving the maximum level of electrical power supply for production processes and everyday needs.

At the present time, all electrical power networks (with the exception of a small portion of industrial and municipal network lines) are concentrated in the USSR Ministry of Energy.

The dynamics of the growth in the length of electrical power transmission lines of the USSR Ministry of Energy is characterized by the data of Table 6.2. The data given here apply only to electrical power transmission lines for regional services. Rural electrical power networks and the lines of industrial enterprises are not included in the indicated figures. The length of rural electrical power networks is especially large, amounting to more than 3,000,000 km at the beginning of 1976.

The electrification of the nation's territory can be characterized by a specific indicator: the ratio of the length of the electrical power transmission lines (in km) to the overall installed capacity of the electrical power stations (in MW).

The dynamics of the change in these indicators over the past years is shown in Table 6.3.

The specific ratio of the length of power transmission lines to the capacity of electrical power stations should, in principle, increase in step with the expansion of electrification and the increasing centralization of the electrical power supply, although it is difficult to establish a precise ratio for this indicator. Specifically, the level of the concentration of production and the specific weight of consumers which use a great deal of electric power will have an impact on this relationship. On the other hand, the dispersion of agricultural power consumers, the presence of small production associations and the high level of electrification in agriculture and everyday service in rural areas produce a higher ratio of power transmission line length to generation capacity.

The necessity for the construction of power transmission lines is due to the construction of large power stations, and in this case, with an increase in the unit capacities of the latter, the voltage, the carrying capacity, and in a number of cases, also the length of the lines increase.

The increase in the voltages for electrical power transmission lines is shown in chronological order in Table 6.4.

Prior to 1950, domestic power transmission lines did not exceed the level achieved abroad with respect to voltage. Beginning in 1956, following the placement of the 400 (500) KV power transmission line in service from the Volzhskaya GES imeni V.I. Lenin to Moscow, the Soviet Union took over first place in the world and continues to maintain this primacy up to the present time.

The first 110 KV power transmission line was constructed from Kashirskaya GRES to Moscow in 1922.

In 1925, along with bringing the Shaturskaya GRES on line at a capacity of 32 MW, a two circuit power transmission line at a voltage of 110 KV was constructed to Moscow. In 1926, the Volzhovskaya GES went into service and electrical power was transmitted from this hydroelectric power station to Leningrad via a two circuit line at a voltage of 110 KV and 130 km long. In 1926, electrical power was transmitted to Gor'kiy from the Gor'kovskaya GRES also via a 110 KV line, and a two circuit 110 KV power transmission line was constructed in the Donbass from the Shterovskaya GRES to the Kadiyevka.

The construction of large hydroelectric power stations, the locations of which were determined not by the placement of electrical power consumption centers, but rather by natural conditions, necessitated the transition to higher voltage power transmission lines at 154 and 220 KV. A voltage of 154 KV was chosen for the transmission of the power of the Dneprovskaya GES which was placed in service.

The greater economic efficiency of the transition from 110 KV to 220 KV was demonstrated through consistent economic calculations. The 154 KV intermediate voltage did not meet the requirements for the rapid rise in the capacity of power stations and the growth in the per unit capacities of power generation equipment, something which was ascertained in the selection of the parameters of the junction line between the Dneprovskaya (where the 154 KV voltage was used) and the Donbass power system. For this reason, the decision was made to construct the intersystem power transmission line at a voltage of 220 KV.

The first 200 KV power transmission line was placed in service in 1933 to transmit electrical power to Leningrad from the Nizhnesvirskaya 10 MW GES. The construction of a 244 km long power transmission line at such a high voltage was a great achievement of Soviet power engineers, and was characteristic of the high scientific and design skills of our scientists and specialists.

Table 6.4

The Increase in the Voltages in Power Transmission Lines

Years	Electrical Power Transmission Line	Voltage, KV	Length, km
1913	"Elektroperedacha"--Moscow	70	70
1922	Kashirskaya GRES--Moscow	110	112
1932	Dneproges imeni V.I. Lenin--Dnepropetrovsk	154	202
1933	Nizhnesvirskaya GES--Leningrad	220	240
1956	Volzhskaya GES imeni V.I. Lenin--Moscow	400 (500)	905
1959	Volzhskaya GES imeni 22nd CPSU Congress-- --Moscow	400 (500)	1,050
1967	Konakvskaya GRES--Moscow	750	90
1962-1967	Volzhskaya GES imeni 22nd CPSU Congress-- --Donbass	Direct current 800 ($\pm$400)	473
1979 (plan)	Itat--Novokuznetsk	1,150	272

The first 220 KV line was constructed in 1936 in the Urals from the Magnitogorsk Metallurgical Combine TETs [heat and electric power stations] for the purpose of transmitting excess power to the region of Vlatoust.

In the middle of 1940, the 220 KV Dnepr to Donbass line was placed in service. The construction of this line pursued the goal of utilizing the peak power of the Dnepro GES to cover the daily load schedules for the Donbass power system.

On the other hand, the transmission of electrical power from the heat and electric power stations of the Donbass to the Dneprovskaya system, which was experiencing a shortage of electrical power, was planned. The coupling link between the systems was the powerful Kurakhovskaya GRES, which was placed in service in 1940.

The length of 220 KV power transmission lines increased from 240 km up to 70,000 km, i.e., by almost a factor of 300, over more than a 40 year period (1933--1975). The length of 154 KV lines likewise increased from 202 km to more than 7,700 km. The increase in the length of the 154 KV lines was related to the construction of the series of Dneprovskaya GES's and the fact that it was not expedient to introduce the 220 KV service into the Dneprovskaya system.

6.2. The Development of Electrical Power Transmission Lines

With the growth of power generation capacities on the whole in the nation and the incrase in the capacity of individual hydroelectric power stations, as well as the lengthening of the distances between them and consumers up to 300 km and more, it became necessary to make a transition to higher transmission line parameters.

Such a changeover was made for the first time in our nation's power engineering when the question of power transmission from the large Volzhskaya GES's to Moscow and the Urals and the Bratsk GES with a capacity of 4,125 MW to Irkutsk was resolved. According to the project plan of Teploelektroproyekt, a two circuit 400 KV power transmission line was constructed in 1956 from Kuybyshev to Moscow having a length (of one circuit) of 905 km with the capability of transmitting more than 1,000 MW of power via the two circuits.

There had been no examples of the construction and operation of power transmission lines at voltages above 380 KV in world practice. Soviet engineers set the task of designing the structural portion of the Kuybyshev to Moscow line with the capability of changing over in the future to a voltage of 500 KV.

A two circuit power transmission line 1,050 km long at a voltage of 400 KV and having a carrying capacity of up to 1,200 MW was planned for the transmission of power from the Volzhskaya GES imeni 22nd CPSU Congress to the Moscow power system.

Operational experience with the two circuit Kuybyshev to Moscow line demonstrated the reliability of the electrical equipment operation as well as the line itself, and also confirm the economic advantages of changing over to the 500 KV voltage.

Based on scientific research and additional design calculations, the possibility of boosting the power transmission line voltage from the Volzhskaya GES's from 400 KV up to 500 KV was established, something which made it possible to increase the carrying capacity of the lines without changing the dimensions by about 30 to 40 percent. The economic efficiency of power transmission lines at a voltage of 500 KV is extremely high, and one can transmit through one of its circuits up to 7 to 8 billion KWH annually over a distance of thousands of kilometers (Figure 6.1).

The electrical power equipment industry, which had mastered the production of the high voltage equipment, was ready to change over to the fabrication of transformers, switches, disconnectors and other electrical equipment for the higher voltage class.

The major goal of the construction of lines from the two high power Volzhskaya GES's (with an overall installed capacity of 4.83 million KW) consisted in transmitting inexpensive hydroelectric power to the Moscow power system. However, considering the fact that it will be expedient in the future to transmit a portion of the electrical power of the Volzhskaya GES's to other power systems, the decision was made to construct three points on the Kuybyshev to Moscow line, and one switching point on the Volgograd to Moscow line. At the present time, these points have been converted to substations in Vladimir and Arsamas on the Kuybyshev to Moscow line, and a portion of the electrical power of the Volzhskaya GES imeni V.I. Lenin is being used in the regions indicated. Lines at this voltage are the connecting links in combining power systems together.

In 1960, the overall length of the 500 KV power transmission lines exceeded 4,000 km, it doubled in 1965 (8,200 km), and by the start of the 10th Five-Year Plan (1976), the length was 18,800 km.

With the appearance of AC power transmission lines at a voltage of 500 KV, the structure of the electrical systems also began to change.

Changes in the functions of the power transmission lines at the different voltages occurred just as before, as a result of expanding the areas which were electrified and the increase in the capacities of the power stations.

For example, at the start of the 1950's, up to 40 percent of the capacities of the electric power stations in many power generation systems with a limited territory which was encompassed by the electrical networks was used at the generator voltage, while the remainder was transmitted via 35 KV lines.

During this period, the 110 KV power transmission lines performed trunk line transmission functions.

By 1950, the length of the 220 KV power transmission lines has increased considerably and amounts to 2,498 km. Over the next 10 years (1950 to 1960), the length of the 220 KV lines more than tripled and reached 15,600 km. Because of this, the 110 KV lines came to be converted to distribution lines and the pace of their growth naturally increased; over the same 10 year period, their length quadrupled and reached 64,600 km.

The change in the length of 35 KV and higher open wire power transmission lines is shown in Table 6.5.

The demand for the transmission of increasing powers over large distances caused a transition to the construction of trunk lines of even higher voltage: 750 -

Table 6.5

The Length of Open Wire Electrical Power Transmission Lines in the USSR at a Voltage of 35 KV and Above

Напряжение, кВ Voltage, KV	(1) Протяженность воздушных линий, тыс. км 1960 г.	1965 г.	1970 г.	1975 г.	1980 г. (план) (Plan)
Total Всего 35—1150	124,4	306,8	445,5	604,8	793,0
Including В том числе:					
1150	—	—	—	—	0,3
750—800	—	0,5	0,6	2,2	3,0
500	4,4	8,2	12,6	18,8	28,0
400	—	0,11	0,55	0,55	0,55
330	1,1	7,3	14,2	19,5	26,0
220	15,6	35,2	50,2	69,5	90,0
154	2,0	5,1	5,8	7,7	8,0
110	64,6	128,1	185,8	244,1	319,0
35	36,7	122,3	175,7	241,6	318,2
(2) *Структура воздушных линий, % к итогу года:*					
220—1150	16,9	16,7	17,5	18,5	19,2
35—154	83,1	83,3	82,5	81,5	80,8

Key: 1. Length of the open wire lines, thousands of km;
2. Make-up of the open wire lines, percentage of the annual total:.

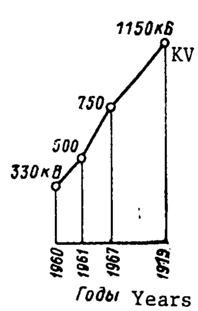

Figure 6.2. The dynamics of the rise in the maximum alternating current electrical power transmission line voltage.

1,150 KV alternating current and 1,500 KV direct current. Such a class of voltages is needed in the creation of the Unified Power System of the USSR, as well as for the transfer of large masses of electrical power from the regions of Siberia and Kazakhstan, where there are rich deposits of mineral fuel, to the nation's central region. The dynamics of the growth in the maximum AC electrical power transmission line voltage is shown in Figure 6.2.

It is to be emphasized in particular that a further expansion of electrification requires not only a transition to higher AC voltage (1,150 KV), but also, DC voltage (2,000 - 2,500 KV).

6.3. The Construction of Electrical Power Transmission Lines

The construction of power transmission lines differs considerably in terms of the technology of the construction and installation work from the building of electrical power stations. The major difference consists in the continuous moving of the construction and installation operations, which require mobile construction and installation mechanisms for their performance. The special features of electrical power network management are reflected in the breakdown of the fixed capital: 80 percent goes for the power transmission lines, 9 percent for buildings, 9 percent for the cost of equipment and 2 percent for other funds.

The construction of power transmission lines and step-down substations on a large scale and with a high degree of engineering sophistication predetermines the implementation of the following primary measures:

--The organization of specialized independent construction and installation organizations;

--Outfitting construction organizations with specialized machines and mechanisms;

--The creation of production bases to produce the support poles for transmission lines and the structures of step-down substations;

--Setting up permanent residential settlements for the families of builders and installation workers on electrical power networks.

In the first stage of electrification, the power transmission lines were constructed by the personnel of various brigades or the operational personnel of power systems. A specialized organization was created in 1946: Glavelektroset'stroy. Some six line installation trusts were organized within this main administration (Moscow, Leningrad, Sverdlovsk, Donbass, Novosibirsk and Tibilisi).

In 1956, because of the large volume of work involved in the construction of the at that time custom made power transmission lines at voltages of 400--500 KV from the Volzhskaya GES's to Moscow, a new main administration was formed: Glavvolgoelektroset'stroy.

Glavsel'elektroset'stroy was created in USSR Ministry of Energy in 1963 to perform the construction and installation work on power transmission distribution lines and transformer substations at voltages of 0.4 to 20 KV in the territory of the RSFSR.

Trusts were organized in the ministries of energy of the Ukraine, Kazakhstan, Uzbekistan and in the main administrations for power engineering and electrification of other union republics for the construction of distribution networks in rural regions.

The breakdown and capacity of industrial enterprises in 1975 are given in Table 6.6, as well as the volumes of construction and installation work in the 9th and 10th Five-Year Plans for the main electrical power network administrations of the USSR Ministry of Energy.

The volumes of electrical power network construction in the last decade have grown significantly (1966-1975), and over this time about half of all of the 35 KV and higher voltage power transmission lines have been built. Capital expenditures for electrical network construction during this period reached 25 percent of all capital investements in electrical construction.

The execution of such volumes of work necessitated the restructuring of electrical power network construction: the increasing of the number of mechanized columns, the creation of bases for the production of steel and reinforced concrete support poles, prefabricated reinforced concrete, as well as bases for the fabrication of spare parts and the repair mechanisms, the creation of plants for the manufacturing of insulation, line and substation fittings, and also outfitting construction organizations with special machines and transport vehicles for the shipment of completely assembled supports.

As a result of the steps which were taken for the industrialization and mechanization of electrical power network construction, the labor expenditures per kilometer of power transmission line was cut in half by 1975, and the level of mechanization of earthmoving and ground preparation and rock work reached 98 percent.

The working and living conditions of power line builders have improved significantly. Enterprises have been created for the fabrication of mobile shops, warehouses, offices, dining halls, recreation and reading rooms and furnished housing to provide normal production, housing and everyday living conditions for the builders on the routes. A housing fund and various institutions which provide the families of power line builders with modern conveniences have been created at the bases for the mechanized columns.

Construction of the supports. The development of support designs has received special attention from the moment the first high voltage electrical power transmission line appeared.

A sound structural design shaped like a candle, which is reliable over many years of service, was selected for power transmission lines at voltages of 6 and 10 KV. On power transmission lines at 35 KV, besides the candle shaped support with a triangular spacing of the wires, a Π-shaped support made of wood has also found wide application.

The greatest change in the structural designs of support occurred in the construction of the 110-150 -- 220 KV power transmission lines.

Structural designs of 110 KV power transmission line supports. Wooden Π-shaped supports with a span between them of 100 to 120 m were used on the first 110 KV power transmission line (from the Kashirskaya GRES to Moscow, 1922). The structural design of these support poles has basically been retained and has been used in construction up to now.

Table 6.6

Volumes of Construction and Installation Work According to Main Network Administrations

Indicators	Glavtsentroelektroset'stroy	Glavvostokelektroset'stroy	Glavsel'elektroset'stroy
Number of:			
Trusts	9	10	29
Mechanized columns	55	52	130
Industrial enterprises	7	8	26
The capacity of the industrial enterprises in terms of:			
Metal structures, thousands of tons	36	80	88
Reinforced concrete structures, thousands of m^3	10	160	-
Preservation of wooden supports, thousands of m^3	-	-	310
Volume of construction and installation work, millions of rubles:			
1971-1975	1,245	1,432.5	1,698.3
1976-1980	1,425	2,052	1,923

Some changes have subsequently been made in the П-shaped wooden support: foundations are used for the poles and the main brace for suspending the two cables has been lengthened.

Long term operational observations have made it possible for Teploelektroproyekt to develop standard type supports for 110 KV power transmission lines.

Cross-shaped tie pieces have been introduced into the structural design of the standard supports to lighten the main cross pieces, where these ties have made it possible to curtail the amount of timber used while maintaining the mechanical strength.

The primary drawback to wooden supports is their rapid decay. Because of the large volume of network construction using wooden supports in the Soviet Union, the question of the necessity of wood preservation of the supports has come up, where preservation was started in 1923. The service life of wooden supports impregnated with wooden preservatives is increased up to 30 to 40 years.

The assembly of wooden supports at their installation site has reduced the cost of the construction and installation work. Setting up plane wood preserving and the introduction of standard supports have made it possible to fabricate all of the parts of the supports at pole preservative impregnating plants.

The expenditures for capital repairs of 35 to 110 KV power transmission lines with untreated supports is more than twice as great as the expenditures for lines with impregnated supports.

A method of wood preservation for the supports of existing power transmission lines while the voltage is applied has been introduced in the Moscow power system, which is accomplished by means of spraying with wood preservative once every six years; this makes it possible to increase the service life of the supports up to 15 to 20 years.

Metal supports for 35 and 110 KV power transmission lines have come to be used simultaneously with wooden ones in practice. The first two-circuit power transmission lines using metal supports in the USSR was constructed in 1925 from the Shaturskaya GRES to Moscow. A tower type support with a vertical arrangement of the wires in a "inverse Christmas tree" configuration was developed for this line. A span of up to 220 m (as opposed to 100 to 120 m with wooden supports) was established for the power transmission line with metal supports, something which made it possible to cut the number of supports per kilometer of line in half.

The use of reinforced concrete for supports in power transmission lines and at substations started a long time ago and has become widespread in a number of countries.

In 1933, the Transcausasus Scientific Research Institute for Hydroelectric Power Engineering (today the GruzNIEGS) developed a method of producing centrifugally cast reinforced concrete supports for 6, 10 and 35 KV power transmission lines. However, the use of reinforced concrete supports even for low voltage power networks was introduced extremely slowly in our country. The first reinforced concrete supports were partially used on the Brotseny--Ventspils 110 KV power transmission line and the supports were assembled from six meter pipes joined together at flanges. The Vasilevichi--Rechitsa--Gomel 110 KV power transmission line was subsequently constructed using single pole centrifugally cast supports.

A major drawback to the supports used on the indicated lines is the reinforced concrete crossbars for stringing the wires, which required that they be joined to the support at the point of installation with a cement solution. Such a method of fastening the parts of reinforced concrete supports at the mounting point precluded year-round construction of power transmission lines.

The structural design of modern reinforced concrete supports makes it possible to use them only as intermediate supports; anchor and corner supports are manufactured of metal just as before. Great changes have occurred in the process of designing and fabricating reinforced concrete supports. In the first stage, sections of reinforced concrete pipes were fabricated with diameters up to 500 mm and lengths up to 6 m. To obtain a support 18 to 24 meters long, it was necessary to join the individual sections together at flanges with the joints made monolithic or assembled by electric welding. It was established in the process of construction and subsequent operation that the given structural design for the joints was unsatisfactory.

Conical type supports were developed in 1955 having an overall length of 20 to 22 meters using centrifugal casting. The supports of this type could be used only for single circuit lines as intermediate supports. The weight of the supports reached 20 to 29 tons. From this point of view, the indicated structural design for the supports was likewise unsatisfactory.

A technology for the fabrication of reinforced concrete poles up to 26 m long was developed in 1956 for two circuit power transmission lines at a voltage of 110 KV. The new support structural design (a weight of 13 tons) was an enormous step foreward as compared to the previous type of support.

Reinforced concrete supports curtail the operational expenditures for their servicing and repair by many times. The volume of earth moving work is sharply curtailed and the operations are completely mechanized in the construction of power transmission lines using reinforced concrete supports.

At the present time, installations for the fabrication of centrifugally cast reinforced concrete supports with an annual productivity of up to 4,000 supports (a concrete volume of up to 10,000 m^3) are in operation in the USSR.

The development of more sophisticated support designs, as well as the replacement of metal anchor and anchor-corner supports by reinforced concrete ones are required to accelerate the introduction of reinforced concrete supports in the construction of 35 to 500 KV power lines.

The structural designs of 154 to 220 KV power transmission line supports. A new type of support, a single circuit portal support with a cross-tie, was developed for the first 154 KV power transmission line (1932).

The operation of portal supports for 154 KV lines for more than 40 years has demonstrated their complete reliability. The construction of a two circuit 154 KV power transmission line was accomplished using three vertical T-chaped poles with cross-arms, on which the two wires were strung. Thus, the wires of the two different circuits were strung on the center poles.

A "wine-glass" type support structure was introduced into postwar construction practice for 154 KV power transmission lines in the Dneprovskaya power system, the advantages of which will be discussed below.

Heavy supports of a spatial structural design were installed on the first 220 KV power transmission line from the Nizhnesvirskaya GES to Leningrad. In the construction of subsequent 220 KV power transmission lines, this complex structural design of the supports was replaced by a simpler one: the portal design. Supports of this type were also developed and installed on the Novomoskovsk--Mosow (1936) and the Rybinsk--Uglich--Moscow (1940) power transmission lines. The use of such supports made it possible to increase the span between them up to 350 m and provide for the appropriate thunderstorm immunity.

During 1947-1948, the project planning organizations developed a fundamentally new structural design of the "wine-glass" type suppprts for a 150 to 220 KV single circuit power transmission line. The supports of this structural design had advantages over the previously used portal type in terms of weight, the size of the span and a reduction in the consumption of metal per kilometer of line length.

The primary drawback to the "wine glass" type support is the impossibility of constructing two-circuit electrical power transmission lines, while in the postwar period, the capacity of electric power stations increased sharply and it was necessary to increase the carrying capacities of through transit power transmission lines to transmit the power. In this regard, the Teploelektroproyekt Institute developed a type of support in 1957 for two-circuit 220 KV power transmission lines with the wires arranged vertically and with one thunderstorm protection cable (of the "barrel" type). The NL2 low alloy steel was used on the lower string in supports of this type, something which made it possible to lighten the support by approximately 25 percent as compared to the similar support fabricated from type St3 steel.

A more economical portal type support was developed for a single circuit power transmission line having cable guys. This type of support makes it possible to increase the span up to 450 m; the intermediate support weight is 23 percent less than the "barrel" type support and 19.5 percent less than the "wineglass" type support.

Assembled type supports. In searches for the most efficient design solutions in selecting the type of supports and curtailing the expenditures for fabrication and installation, work has been done in recent years on the replacement of welded metal supports with the elements of the suppports joined together with bolts.

With the dissemination of electric welding and the organization of industrial methods of assembling and installing supports, riveted structures were gradually replaced by electrically welded sections with their subsequent assembly at the installation site of the supports. Plans for the fabrication of welded support structures should be equipped with powerful cranes, have a large and sophisticated welding capability with a considerable electrical power consumption for welding.

The product output from the areas of plants, because of the bulky nature of the structures, amounted to 0.7 to 1.5 tons from one square meter. Spatial welded structures did not make it possible to load the railroad rolling stock by more than 30 percent of the carrying capacity of a car, or more than 40 percent of the load capacity of motor vehicle transportation. The shipment of welded sections of metal supports required special motor vehicle trailers and heavy motor vehicles. It was necessary to have powerful cranes on tractors for the installation of these supports on the routes of power transmission lines.

Considering the deficiencies of welded structures for supports and making use of the experience of foreign construction, the decision was taken in the Soviet Union to conduct experimental work on the fabrication of metal supports of individual components, with their assembly on the power transmission line route using bolts.

The first 220 KV power transmission line, 92 km long and using assembled supports, was constructed in 1958 from the Yuzhno-Ural'skaya GRES to Chelyabinsk. The two types of supports, the welded structure and the assembled one, are compared in Table 6.7. The labor outlays for the fabrication of assembled supports were curtailed by 18 percent, while the cost of the work force was reduced by 24 percent. The overall expenditures per ton of assembled structure (including the cost of transportation to the designated station) were curtailed by 13 percent. The installation of the assembled structure supports yielded a savings of about 1,000 rubles as compared to a welded structure support (Table 6.8).

The major types of 500 KV power transmission line supports are intermediate supports: П-shaped, portal, anchor and anchor-corner pole support.

The consumption of metal for supports, as well as concrete and reinforced concrete for foundations and footings is of great importance in the construction of 500 to 750 KV power networks. Comparative data on the consumption of metal per kilometer of line in the USSR and other nations of the world are given in Table 6.9. It can be seen from these data that the supports for 500 and 750 KV power transmission lines in the Soviet Union, with the exception of the Dnepr-Donbass line, are more economical in terms of metal consumption per kilometer of line than the supports used by the capitalist nations with advanced electrical power engineering, for example, the U.S. and Canada.

The major conditions which govern the weight of support structures with a specified metal quality are the design standards for wind velocity and amount of icing.

The first years of the operation of the Volzhskaya GES imeni V.I. Lenin to Moscow power transmission line demonstrated its sufficient reliability and durability.

Changes were made in the structural design of the supports for the Volzhskaya GES imeni V.I. Lenin to Tatneft' line: cable guys were used on the intermediate portal type supports. The use of cable guys on 500 KV power transmission lines yields a savings in metal consumption of up to 20 percent, and the savings in

Table 6.7

Comparative Data on the Two Types of Supports

Indicators	Welded П-shaped support	Assembled portal support
Span, meters	385	385
Design wind velocity, m/sec	25	25
Weight of the supports, kg	6,026	5,775
Height of the support, m:		
Total	25.5	25.5
Up to the cross-arm	21.5	21.7
Number of welded sections, pieces	13	-
Maximum weight of the sections, kg	1,168	-
Weight of the packets of semifinished products, kg	-	420-2,676
Electrical power consumption for fabrication, 10^3 KWH	366	64

Table 6.8

Expenditures for the Installation of the Different Types of Supports

Kind of Work	Expenditures for the Installation of the Supports, Rubles	
	Welded Support	Assembled Support
Excavation work and grounding	123	127
The installation of support foundations	1,916	1,388
Assembling the supports	2,458	2,010
Transportation	126	126
TOTAL	4,731	3,751

terms of the capital expendtitures are considerably less because of the high cost of the cable as compared to the usual ferrous metal used in the fabrication of the supports.

Reinforced concrete supports were installed for the first time in Siberia in 1960 for a 500 KV line, something which was a great engineering achievement.

The increase in the volume of the steel reinforced concrete use in thousands of m^3 for the supports of power transmission lines at voltages above 35 KV can be seen from the following data:

1955	1960	1965	1970	1974
0.52	26.1	107.0	168.0	158.0

Table 6.9

The Metal Used in 500-750 KV Power Transmission Lines

Countries and Power Transmission Lines	Year Placed in Service	Line Voltage, Kilovolts	Metal Consumption per Kilometer of Line, Tons
USSR			
Zainskaya--Kuybyshev	1969	500	23.5
Novolipetsk--Orel	1975	500	22.1
Nazarovo--Itat	Planned	500	14.3
Konakovo--Moscow	1970	750	30.0
Dnepr--Donbass	1973	750	54.9
Konakovo--Leningrad	1975	750	29.7
U.S.			
Makalach--Toluka	1970	500	28.3
Oconi--Newport	1973	500	43.5
Govin--Margiville	1973	750	49.0
Wilton--Plano	1975	750	63.0
Canada			
Hen--Kleynbig	1966	500	17.0
Minekugen--Lewis	1971	750	59.8

At the present time, the specific weight of steel reinforced concrete supports for 35 to 500 KV power transmission lines amounts to 75-78 percent, 21-23 percent for metal supports and 1 to 2 percent for wooden supports.

The protection of electrical power transmission lines. The protection of power transmission lines (relay protection and protection against overvoltages) is one of the important components in the operation of electrical power networks and in assuring their operational reliability, and also, consequently, in assuring continual electrical power supply to the users.

Cables and dischargers are used as protection against atmospheric overvoltages. The most effective protection is covering the electrical power transmission line with metal cables over the entire line length (in the case of metal supports) and at a distance of 2 km from the generating sources or step-down substations (in the case of wooden supports).

Cable protection with good grounding provides for complete thunderstorm immunity of electrical power transmission lines. To smooth out the leading edge of the overvoltage wave, dischargers of various systems which protect the equipment against damage are installed at substations.

Because of the dead ground system adopted for the neutrals of transformers, arc suppressing coils have not become widespread in the Soviet Union.

Relay protection of power transmission lines responds to nonsteady-state emergency operational modes of the power system. In the first developmental stage of protection prior to 1930-1935, the simplest current protective devices were employed in power systems, since the predominant types of lines used for power transmission were radial and ring lines.

Fast response differential and high frequency protection came to be introduced in electrical power networks during 1935--1945. Since relay protection should provide for dynamic stability of the power systems, this necessitated the acceleration of the action of protective relays and disconnect devices. As a result of the introduction of highly sensitive and high speed protective devices, the percentage of proper protective responses has continually increased; thus, for the largest power system, the Moscow system, the percentage of correct protective actions increased from 85 percent in 1935 up to 100 percent at the present time.

High speed, high frequency and differential protection for power transmission lines and power generating sets provides for complete selectivity, speed in the elimination of the emergency modes which arise and guarantees normal operation for various changes in the configuration of the power network.

The next stage in the development of electrical power network protection is characterized by the introduction of automation, which acts in conjunction with the protection. Repeat connection automats, automats for connection of a stand-by unit and other automatic devices are widespread in the Soviet Union's electrical power networks.

The reliability of AC electrical power networks can be improved by taking a number of measures. For the most important consumers, who do not permit an interruption in the power supply, reliability is increased by bringing in electrical power from different generating sources or substations. A good tool for improving the reliability of electrical power supply is the repeat connection automats which have been developed in the USSR. It has been established by investigation that of 100 emergency disconnections of consumers, when they are reconnected after a few seconds, normal electrical power service is restored in 80 cases without disruption of the generation process. Repeat connection automats have been widely introduced in the electrical power networks of our country, and their modernization with a transition to phase by phase connection have additionally increased the reliability of the electrical power supply.

6.4. The Prospects for the Expansion of Electrical Power Transmission Lines

As was shown above, the development of power networks in a quantitative and a qualitative sense should take place synchronously with the expansion of power engineering and electrification. Thus, with an increase of one megawatt in capacity, the length of power transmission lines at voltages of 35 KV and above increase by approximately 2.8 km. Thereafter, the ratio of 1:2.8 should change in the direction of an increase in the electrical power transmission lines placed in service.

A second problem with the development of electrical power networks is further increasing the parameters of power transmission lines. Lines with high parameters are also needed for the resolution of the problem of transmitting a large amount of electrical power from the eastern regions to the center of the nation over a distance of 3,500 km.

The formation of the USSR Unified Power System entails the solution of a number of complicated scientific and engineering problems. The most important problem of the USSR Unified Power System is providing for the static and dynamic stability of such a high capacity and complex system. One of the ways of solving this problem can be the use of direct current lines or inserts.

Such a design, for example, was adopted in the USSR to Finland electrical power transmission line, the construction of which is being accomplished in line with an accord concluded between the nations. A rectifier--converter installation is employed to realize intersystem electrical power transmission, joining the high power generating associations: the USSR Unified Power System and the Finland system.

When a direct current link is present in an intersystem coupling system, the transmitted power practically does not depend on the change in frequency and the voltage level in the power system.

The basis for the further expansion of the sphere of electrification should remain the system of transmitted electrical power using alternating currents. The advantages of this electrical power transmission system are indiputable in electrical power networks over the entire range of voltages, starting with low voltage 0.4 KV transmission lines and running up to 1,150 KV, i.e., from supplying electrical power for individual users up to intersystem interfaces with a

Table 6.10

The Parameters of AC Power Transmission Lines

(1) Напряжение, кВ	(2) Наибольшая передаваемая мощность на одну цепь, МВт	(3) Наибольшая длина передачи, км
110	25—50	50—150
220	100—200	150—250
330	300—400	200—300
400	500—700	600—1000
500	700—900	600—1200
750	1800—2200	800—1500
1150	4000—6000	1200—2000

Key: 1. Voltage, KV;
2. Maximum transmitted power on one circuit, MW;
3. Maximum transmission length, km.

length of up to 2,000 km and more. Technical progress in alternating current electrical power transmission in the future consists in further increasing the parameters of the voltage, the transmitted power on one circuit and the electrical power transmission length.

The relationships between the indicated alternating current power transmission line parameters can be seen from the data of Table 6.10.

The choice of the electrical power transmission line voltage is determined by economic calculations, taking into account the transportation of fuel resources.

As was indicated above, in step with the increase in power generation capacity, a change occurred in the functions of the transmission lines at various voltages: trunk lines with lower parameters changed over to the class of distribution lines. This progressive regular feature will also be retained for the next 10 to 20 years in the immediate future.

At the present time, the functions of alternating current trunk electrical power transmission lines are performed by 330, 500 and 750 KV lines. Lines at 750 KV have been constructed in the combined power systems of the South and Northwest and Transukraine 750 electrical power transmission system (Figure 6.3 and 6.4 [not reproduced]) with a length of more than 1,100 km and a carrying capacity of 2,500 MW. The latter crosses the central regions of the Ukraine from east to west and reinforces the coupling between five regional power systems. The high voltage line consists of two sections: Donbass--Dnepr---Vinnitsa and Vinnitsa--Western Ukraine Substation. The second portion of the lines is an element of the international 750 KV Vinnitsa (USSR) to Albertirsha (Hungarian Peoples' Republic) power transmission system.

A 750 KV line between Leningrad and the Konakovskaya GRES was constructed in 1975 to feed power from the Leningrad AES [Nuclear Power Station] to the Tsentr Combined Power System.

During the 10th Five-Year Plan and after, intersystem coupling lines will be created between the Tsentr and South Combined Power Systems. Power will be supplied from the new largest AES's which are under construction: the Chernobyl'skaya, Kurskaya and Smolenskaya, where the power will also be transmitted via 750 KV electrical power transmission lines. The construction of 750 KV power transmission lines between the Unified Power System of the USSR and the Combined Power Systems of the CEMA member nations is of great importance.

At the start of 1978, more than 1,500 km of AC 750 KV power transmission lines were in service, and during the 10th Five-Year Plan, more than 1,000 km of such lines will be placed in service.

Thus, a further increase in the parameters of electrical power transmission lines is anticipated in the alternating current power networks prior to 1980.

The 750 KV power transmission lines have become quite widespread in the U.S. and Canada. The first 765 KV power line in the U.S. was placed in service in 1963, and by the start of 1976, the overall length of these lines reached 2,000 km. In canada, 750 KV lines have become more widespread and their overall length at the present time exceeds 5,000 km. Apparently, 750-765 KV electrical power transmission lines will be further expanded in the future.

The growth in the unit capacities of power stations up to 4 to 8 million KW and the necessity of transporting about 4 to 6 million KW of power requires a further increase in the voltage of alternating current lines.

As was indicated above, the next voltage stage in the USSR has been chosen at 1,150 KV. The construction of lines of this type requires scientific research and developmental design work in depth.

The solution of the problem of the harmful effect of an electrical field on man presents considerable complexity. Studies have been performed, as a result of which, public health safety standards have been established for the electrical field intensity which assure the safety of the personnel servicing lines and substations, as well as the population in the region affected by open wire lines. Research is continuing in this direction.

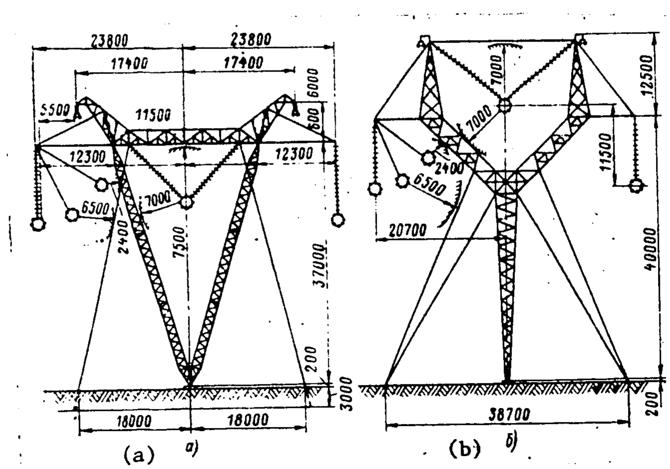

Figure 6.5. The intermediate supports for an 1,150 KV power transmission line.

Key: a. Horizontal arrangement of the phases;
b. Triangular arrangement of the phases.

Studies are upcoming on reactive power compensation, voltage regulation, the determination of the optimum cross-section of wires, the reduction of corona losses, etc.

Based on the research which has been done with a test facility, the basic parameters of an experimental industrial open wire 1,150 KV line between Itat and Novokuznetsk have been determined (the initial section of the line joining the combined power systems of Siberia, Northern Kazakhstan and the Urals): the supports for the open wire lines are bolted metal supports with hot dipped zinc galvanizing; the intermediate supports using guys with a horizontal arrangement of the phases at a height of 37.0 m and also with a triangular configuration of the phases at 40.0 m (Figure 6.5); the wires are type AS-300/39, with 8 conductors per phase and the spacing between them is 40 cm. Depending on ecological requirements, the overall spacing from the ground has been adopted as: 14.5 m (20 KV/m) in unpopulated terrain and in a populated area, 17.5 m (15 KV/m).

Later, 1,150 KV power transmission lines will be constructed to strengthen the linkage between the combined power systems of the Urals, Povolzh'ye and Tsentr.

The alternating current 1,150 KV voltage level presents considerable complex problems for the construction of substations. The purpose of finding ways of eliminating these difficulties, research is underway into the utilization of elemental gas as insulation, something which will make it possible to change over to enclosed distribution and switchgear for substations.

6.5. Direct Current Electrical Power Transmission Lines

The transmission of electrical power using direct current is not a new idea: moreover, the first electrical power transmission used direct current. Prior to the invention of transformers, synchronous generators and electric motors using alternating current, the electrical power consumed for the needs of industry and transportation was direct current power. With the increase in the scale of electrical power generation and consumption, and the expansion of the sphere of power utilization in various sectors of the national economy, direct current could not meet the demands placed on it because of the specific features inherent in it. The specific weight of direct current in power consumption (electrolysis, electrochemistry, motors with a wide speed control range, etc.) amounts to about one-fifth of the overall energy balance.

For a long time, a delaying factor for the introduction of direct current was also the fact that the process of transforming alternating current to direct current was realized inefficiently using the following scheme: a DC motor turned a DC generator, which powered all of the devices using direct current. The efficiency of such a configuration is extremely low, considering the electrical power losses in the electric motor and the generator, as well as the mechanical losses in the coupling devices. A return was made to the notion of direct current electrical power transmission at high voltage in the middle of the 1930's, with the appearance of high power mercury vapor rectifiers. Later, high voltage thyristor high power rectifiers were developed.

The following can be numbered among the advantages of a direct current electrical power transmission line:

--The electrical power transportation is accomplished using two wires instead of three (in the case of alternating three-phase current), something which makes it possible to reduce the consumption of nonferrous metal by one-third;

--The supports for direct current lines, other conditions being equal, are significantly lighter because of the lesser weight of the wires;

--There are no losses for remagnetization of the conductors, since direct current does not change direction;

--Direct current power transmission can be controlled by equipment, something which makes it possible to change power overcurrents in electrical power networks;

--The possibility of asynchronous running of generators when direct current sections are present in alternating current lines;

--No increase is needed in the spacing of the wires from the ground based on ecological considerations, as is the case in high voltage alternating current lines.

The following number among the drawbacks to direct current electrical power transmission lines:

--The presence of two substations (rectifier and inverter substations) has a significant impact on the cost of the power transmission lines;

--The capability of using lines only for through transmission, without tapping off electrical power along the route.

The positive features of direct current make it possible to design an electrical power transmission system for higher voltages. This specific feature, in conjunction with the lower losses, makes it possible to transmit electrical power using direct current over long distances.

Based on theoretical studies, planning calculations and the experience acquired in the operation of experimental test electrical power transmission systems, it has been determined that the economically advantageous length of direct current lines runs from 1,500 km and up when transmitting more than 2,500 MW of electrical power.

It is apparent that the power resources of Siberia, Kazakhstan and Central Asia, which are 2,500 to 3,500 km distant, cannot be transported to the European portion of the nation using alternating current power transmission lines at a voltage of 1,150 KV (up to 6,000 MW over a distance of up to 1,200 km).

Thus, the transmission of electrical power from the eastern regions of the nation to the center is possible via high voltage direct current lines.

The first direct current line was placed in service in our country in 1950 from the Kashirskaya GRES to Moscow. The first electrical power transmission parameters were rather modest: a voltage of 200 KV ($\pm$ 100 KV), a transmitted power of 30 MW and the line was 112 km long. A single core aluminum cable with a cross-section of 150 mm^2 with paper insulation was used for the construction of the line.

Mercury vapor single anode rectifiers were installed at the converter substations in Kashira and Moscow, where these rectifiers were designed for a maximum current of 150 amps and an inverse voltage of 130 KV (peak). The mercury vapor rectifiers had a very high efficiency, equal to 0.996.

For the purpose of conducting a deep and multifaceted study of the problem of direct current power transmission, the Scientific Research Institute for Direct Current (NIIPT) was created in Leningrad.

The possibility of tapping off power from direct current power transmission lines under certain conditions was demonstrated through the research work performed by the NIIPT and the ENIN [Power Engineering institute imeni G.M. Krzhizhanovskiy].

The research work which has been done and the experience acquired during long term operation of the DC Kashira-Moscow power transmission line served as the basis for the planning and design of the next electrical power transmission system of higher parameters.

The development of the structural design and the mastery of the fabrication of mercury vapor rectifiers with a current capacity of 900 amps and a voltage of 130 KV have opened up the path to the design of power transmission lines at voltages up to 800 KV and a transmitted capacity of up to 1,000,000 KW.

The concept of the creation of intersystem coupling was taken as the basis for the choice of the new DC electrical power transmission system.

An electrical power transmission line joining the powerful Donbass power system with the Volgograd power system was chosen on the basis of these prerequisites.

The utilization of the Volzhskaya GES imeni 22nd CPSU Congress having a capacity of 2,541 MW to cover the peak portion of the electrical power load of Donbassenergo on one hand, and the feeding of additional base power into the Volgograd power system from the thermal power stations of the Donbass on the other hand would permit an increase in the reliability and economy of the operation of the two associations.

The Volgograd to Donbass (Mikhaylovskaya substation) DC power transmission line was planned for the following parameters: a voltage of 800 KV ($\pm$ 400 KV) and a transmission power of 750 MW for a transmission length of 473 km. The first stage of this line at half of the voltage and transmitted power design parameters was placed in service in 1962. Starting in 1968, the Volgograd to Donbass line has operated at the design parameters (Figure 6.6).

Mercury vapor rectifiers of an improved structural design for a maximum current of 900 amps and a voltage of 130 KV, with eight bridges at each end and the bridges connected in series were installed at the converter substations of the indicated power transmission line at Volgograd and at the Mikhayloskaya substation.

An operational mode was worked out on the Volgograd to Donbass line for the mercury vapor rectifiers with large fluctations in the loads, and especially where the power was transmitted both in the forward direction and in the return direction.

The mercury vapor rectifiers produced by the Tol'yattinsk electrical equipment plant have on the whole demonstrated high quality and adequate durability. Along with this, their weak point, "inverse firing", has been confirmed. The drawbacks of mercury vapor rectifiers do not permit achieving the optimum engineering and economic indicators for power transmission. The replacement of some of the mercury vapor rectifiers on this line with high power semiconductor converters has made it possible to increase its operational reliability and efficiency while providing for stable power overcurrents of the South and Tsentr of up to 800 MW.

Operational observations on the Kashira-Moscow and Volgograd-Donbass power transmission lines have shown that mercury vapor rectifiers (the best models) can operate reliably for 15,000 to 18,000 hours. This between repairs period is completely adequate for normal operation of electrical power transmission lines, also including the requirements placed on through working and intersystem links.

The successes achieved in the design of germanium, and especially, silicon rectifiers have made it possible to move onto the design of high power semiconductor converters for ultralong range DC electrical power transmission lines.

The increasing shortfall in the fuel-energy balance of the European portion of the nation has posed in all its sharpness the question of the necessity of transporting energy resources, primarily, from Kazakhstan (the Ekibastuz basin) and Siberia (Kansko-Achinsk basin).

The shipment of multiple ash or moist coals to Tsentr is not economical or is extremely undesirable for many reasons. The solely acceptable transportation for energy resources under these conditions is electrical transportation, by means of DC power transmission lines.

The Energoset'proyekt Insitute has developed a project plan for a 2,414 km long DC line between Ekibastuz and Tsentr for the pratical solution of the problem of transmitting electrical power from Northern Kazakhstan.

The 1,500 KV (± 750 KV) voltage level of the Ekibastuz-Tsentr power transmission line at a transmission power of 6,000 MW (at the sending end of the line) makes it possible to transmit about 36 billion KWH annually to the central regions (at the receiving end of the line). The technical economic parameters of this custom design DC power transmission line assure its efficiency and advantages over transportation of Ekibastuz and Kuznetsk coals to Tsentr, as well as compared to substituting nuclear power station capacity at the present state of the art.

A provision is made in the project plan for the Ekibastuz-Tsentr line for the installation of high voltage, high power thyristor rectifiers at the conversion substations. The rectifier bridge is designed for a current of 2,000 amps and voltage of 187.5 KV for the rectifier substation and 168 KV for the inverter substation. A cascade circuit configuration of four bridges provides for the nominal pole voltage at the sending end of the line of 187.5 x 4 = 750 KV relative to ground.

The line consists of two circuits ($\pm$) with a dead grounded neutral. In the case one circuit (pole) fails, the line can operate using a pole--ground circuit configuration with a half load of 3,000,000 KW.

The line efficiency, taking into account the losses in the converters, is equal to 85 percent.

When the combined Tsentr and Northern Kazakhstan power systems are joined together by means of the Ekibastuz-Tsentr line, a so-called intersystem effect of 1,400 MW will be obtained by virtue of the utilization of the difference in the time of occurrence of the load maxima in the combined power systems. The size of the reserve capacities can be reduced by this amount.

Technical economic calculations performed by project planning and scientific research institutes have demonstrated the high effectiveness of the construction of this line. Thus, the cost of conventional fuel, taking into account railroad transportation expenditures, amounts to: Ekibastuz coal, 14-16.5 rubles/ton, Kuznetsk coal, 18-22 rubles/ton, Donetsk coal, 20-23.5 rubles/ton, while the transmission of electrical power via the Ekibastuz-Tsentr 1,500 KV line at 6 million KW will cost 11 to 12 rubles/ton.

One ton of conventional fuel in the nation's Tsentr, in the case of the transmission of power resources in the form of electrical energy, proves to be considerably less expensive than the utilization of any kind of solid fuel. The referenced cost of the electrical power transmitted by the line will be 0.93 kopeck/KWH, and when Ekibastuz coal is shipped by rail as far as the Volga, the cost is 1.04 kopeck/KWH, i.e., 10 percent more expensive.

The ultrahigh voltage DC lines, besides transmitting a large amount of electrical power over long distances, in an optimum combination with high capacity AC power transmission systems, will play an important role in the next 20 to 25 years in the further development of the USSR Unified Power System, as well as in improving the nation's power supply. The solution of the questions of assurring electrical power supply reliability and quality (maintaining the frequency and voltage stable within a narrow range) which are becoming increasingly complex and important (in step with the development of the USSR Unified Power System) is of enormous national economic importance. DC lines at voltages up to 2,500 KV, by virtue of the large capacity as compared to AC ultrahigh voltage lines, will apparently be able in the future to find wide application in the feeding of power to the USSR Unifed Power System from nuclear power generating centers, which, will probably be built remote from densely populated regions of the nation, because of the planned introduction of fast neutron nuclear reactors incorporated in a complex with nuclear fuel cycle enterprises.

The creation of DC power transmission lines at a voltage of 2,500 KV requires the solution of a number of major scientific and engineering problems. It is necessary to perform a complex of studies and developmental work on high voltage and conversion equipment, as well as compute the operating conditions for 2,250--2,500 KV direct current electrical power transmission. In this regard, direct current power transmission at the indicated voltage and with a carrying capacity of from 13 to 40 million KW is to be substantiated in engineering and economic terms. Also ahead is the working out of the engineering requirements for the main electrical equipment at these voltage and power levels.

For ultrahigh voltage direct current lines, it is necessary to establish the design principles for the automated control systems.

In this sense, the construction of the Ekibastuz-Tsentr DC power transmission line for a voltage of 1,500 KV is to be considered an obligatory intermediate step for the transmission to lines at a higher voltage.

During the last decade, direct current power transmission lines have been constructed or are under construction in a number of countries. At the present time, 10 DC power transmission lines have been built abroad with an overall carrying capacity of somewhat more than 6 million KW. In the U.S., the Pacific Ocean direct current line with a power of 1,440 MW, a voltage of 800 KV and a length of 1,370 km was placed in service in 1970 for the transmission of electrical power from a GES in the state of Oregon to the Los Angeles power system. In Canada, two direct current line circuits at a voltage of 900 KV, with a carrying capacity of 1,625 MW for each circuit and a length of 920 km were constructed in 1970-1972 for the transmission of electrical power from powerful GES's in the northern part of the nation to load centers. A 1,066 KV direct current line was placed in service in 1975 from the Kabora GES-Bassa (Mozambique) as far as the border with the Republic of South Africa, and its carrying capacity is 1,920 MW with a length of 1,450 km.

According to existing data, a number of high power DC electrical power transmission lines are planned for construction in a number of the nations of the world by 1980 (Table 6.11).

By comparing the data of the existing, under construction and planned foreign direct current lines with the parameters of the Ekibastuz--Tsentr power transmission line, the conclusion can be drawn that the Soviet Union occupies the leading position in the field of direct current electrical power transmission over long distances.

Direct current transmission lines will be further developed in the future in the power engineering of the Soviet Union.

The parameters of direct current lines in the USSR which have been built, are under construction and are planned, are shown in Table 6.12.

The Ekibastuz--Tsentr and Itat--Tsentr (Kansko-Achinsk coal basin) power transmission lines are through working lines and serve for the transmission of electrical power to the nation's central region. Along with this, the lines form a firm framework for the USSR Unified Power System along with the future altnernating current lines at voltage of 750 to 1,150 KV.

Table 6.11

High Voltage Direct Current Power Transmission Systems Planned to Go into Service Abroad by 1980

Power Transmission Lines, Country	Line Parameters: Voltage, KV	Power, MW	Length, km
Silailo--Meade (U.S.)	±400	1,440	1,320
Center--Duluth (U.S.)	±250	500	734
North Dakota-Minneapolis (U.S.)	±450	-	672
Norway--Denmark	±250	500	245
Inga--Shaba (Zaire)	±500	560	1,760
Hokaido--Honsu (Japan)	±125	150	193

Table 6.12

USSR Direct Current Electrical Power Transmission Lines

Power Transmission Lines	Year Placed in Service	Line Parameters: Voltage, KV	Power, MW	Length, km
Kashirskaya GES--Moscow	1959	200(±100)	30	112
Volzhskaya GES imeni 22nd CPSU Congress--Donbass	1962-1965	800(±400)	750	473
Ekibastuz--Tsentr	-	1,500(±750)	6,000	2,414
Itat--Yug	-	2,250(±1,125)	13,000	3,500-4,500
Itat--Tsentr	-	2,500(±1,250)	40,000	

6.6. Problems in the Utilization of Superconductivity for Electrical Power Transmission

Under the conditions of the considerable increase in electrical power generation, the necessity arises of searching out new technical ways of transmitting electrical power, for the purpose of significantly increasing the transmitted capacities and curtailing the expenditures for their transportation.

An experimental line section 850 m long at a voltage of 2,300 KV is under construction in the U.S. However, it is necessary to keep in mind the fact that the use of open wire power transmission lines with high and ultrahigh voltages is limited, on one hand, by the dielectric properties of air, and on the other, by the ecological requirements, especially in densely populated regions.

Further searches for possible ways of substantially boosting the carrying capacity of cable lines while simultaneously reducing the specific referenced expenditures have lead to the elimination of the traditional method of removing the heat from current carrying cores and to the development of a fundamentally new kind of cables: cryogenic, in which the heat is removed by means of cryogenic gases or liquids at a temperature below 100 °K. Cryogenic cables are broken down into cryoresistive and superconducting types.

Plans for superconducting cables are being worked out at the present time in the leading industrially developed nations. The increase in the carrying capacity of the cables is realized through a sharp increase in the working current up to 10^4 to 10^6 amps while retaining or even reducing the working voltage as compared to the voltage classes which have been mastered at the present time. A significant increase in the transmitted capacity as compared to conventional cable makes it possible to reduce the specific referenced expenditures at power levels commensurate with the ultimate values for cables having paper-oil insulation.

The most promising applications areas for superconducting power transmission lines are deep high power entrances into large cities and industrial centers as well as outlets from large AES's, TES's and GES's.

Of great interest for the USSR is the transmission power to the European area from the coal deposits of Siberia via trunk lines with a carrying capacity on the order of tens of millions of kilowatts per circuit.

However, it is necessary to perform an enormous volume of scientific and engineering work, and first of all, solve the problems of the high operational reliability and reparability of the lines for the realization of cryogenic cable lines.

Experimental and theoretical research has been underway on the creation of superconducting power transmission lines since 1970 at the ENIN imeni G.M. Krzhizhanovskiy.

The research is being conducted in the following areas:

--The utilization of supercritical helium as the primary electrical insulating medium for the primary coolant;

--Eliminating the requirements of cryostatic stabilization of the current carrying cores and considering as a whole the operating superconducting power transmission lines with variable electromagnetic and thermal field parameters;

--Considering the current carrying cable system as symmetrical in electrical and thermal senses;

--Equalizing the temperature over the length of the cable line and improving the regulation efficiency through the insertion of accumulators, spread along the length of the line, in the form of mechanical fittings or dielectric materials.

One of the most important trends in the work being peformed at the ENIN is the research into the technical economic indicators of superconducting alternating and direct current electrical power transmission lines. In this case, major attention is being devoted to alternating current transmission lines, since the results obtained in the study of AC lines can be easily extended to direct current lines because of the common features of the cryogenic jacket, the refrigeration system and other components. The major component of superconducting power transmission lines is the superconducting cable, which essentially also determines the cost of power transmission through these lines.

Calculations of an optimization problem have been made using the example of a three-phase superconducting cable, something which makes it possible to extrapolate the results obtained to more modern structural designs. The specific referenced expenditures have been obtained as a function of the voltage in a range of powers from 0.5 GVA to 10 GVA. If the cost of existing trial production is taken as the upper limit for the fabrication cost for a superconducting cable (1,200 rubles/m), and taken as the lower limit is the maximum real cost of fabricating oil filled cables (200 rubles/m), then the specific referenced expenditures in rubles/(MVA · km) for superconducting power transmission lines with a cable consisting of three single phase coaxial cables in one cryogenic shell with phase by phase shielding, will be as follows:

From 700 to 400 at 0.5 GVA
From 400 to 200 at 1 GVA
From 160 to 100 at 3 GVA
From 110 to 75 at 5 GVA
From 75 to 60 at 10 GVA

Among the individual components, the cost of the superconductor amounts to no more than 5 to 7 percent of the overall cost. The percentage for the helium and the helium refrigeration equipment in the overall expenditures does not exceed 10 percent.

The cost of the cold region of the cable, without taking into account expenses for fabrication and installation, amounts to no more than 35 percent of the overall cost of the superconducting power transmission line.

A comparison of the technical economic indicators of oil filled, gas filled and superconducting electrical power transmission lines shows the absolute superiority of the latter for transmitting powers above 1.5 to 2 GVA.

The status and level of the scientific research and experimental work in a number of countries and the Soviet Union is such that there is confidence in the creation of industrial cables in the period before 1990.

Scientific studies and experimental work have made it possible to develop a project plan for an industrial cryogenic cable line one kilometer long. This superconducting line will be constructed at the Kozhukhovskaya substation of the Moscow Power System in the current five-year plan. In structural terms, this cable lines takes the form of a rigid pipe system, assembled from prefabricated sections. The current carrying portion consists of copper tubes with external diameters of 112 and 80 mm, on which a superconductor of niobium stannide 12 micrometers thick is applied in the form of a thin film on the outer and inner surfaces. The coolant for the primary loop is helium, cooled to a temperature of 7.2 °K; liquid nitrogen circulates in the secondary loop (following the vacuum jacket). The line voltage is 10.5 KV and the line current is 10 KA. The high insulation properties of liquid helium were also established by the studies. The optimal value of the breakdown voltage which is equal to 230 to 250 KV/cm occurs for a helium density in a range of 0.03 g/cm^3.

Intense work is under way in many nations of the world to study superconductivity and design a superconducting cable. The work is being pushed especially hard in the U.S., the Federal Republic of Germany and Japan.

Brookhaven National Laboratory (U.S.) has drawn up a project plan for the construction of flexible three-phase superconducting cable lines 35.5 km long (Shoreham—Holbrook) at a voltage of 138 KV with a tranmsitted power of 1.3 GVA and a working current of 5.5 KA. With overal expenditures of 67.1 million dollars, specific transmission cost amounts to 730 dollars/(MVA · km). According to a project plan for a superconducting cable line 68.4 km long (Shoreham--—Rollanroyd) at a voltage of 345 KV with a working current of 4.0 KA and a transmitted power of 2.4 GVA, the specific transmission cost amounts to 615 dollars/(MVA · km).

The "Union Carbide" company (U.S.), according to calculations performed in 1969, ascertained the following parameters in the design of a rigid three-phase superconducting cable:

Voltage, KV	60	138	230	345
Current, KA	3.55	7.1	11.8	17.78
Power, GVA	0.423	1.69	4.71	10.59
Specific cost, dollars/(MVA · km)	1,070	360	130	125

Calculations performed at the ENIN for various types of three-phase rigid coaxial superconducting cable yielded the following results:

Voltage, KV	110	110	220	220	330
Current, KA	2.62	3.24	7.85	13.1	17.5
Power, GVA	0.5	1	3	5	10
Cost of the materials and refrigeration equipment, rubles/ /(MVA · km)	490	370	200	160	112
Specific cost, rubles/ /(MVA · km)	1,900	1,100	550	420	310

It can be seen from the calculation data given above that with an increase in the voltage and transmitted power, the specific cost falls off sharply. This indicates that a superconducting cable should be designed for the transmission of large power levels.

Superconductivity also opens other possibilities for power engineering: the design of storage devices and cryogenic converters for electrical energy. Since there are practically no electrical power losses in superconductors, one can design electrical energy storage devices which operate in a charge--discharge cycle. In particular, one can use a superconducting direct current cable for this purpose, where a cable ring is created. Such a storage device will be charged during the minimum load hours, and discharged during the peak load hours. The economic efficiency of a cryogenic store will be quite high, since besides storing electrical energy, it will permit equalization of the load of thermal power units.

CHAPTER SEVEN

POWER SYSTEMS

7.1. Power Systems: The Basis of Electrification

The generation and consumption of electrical power takes place in a continuous process without intermediate steps. In contrast to other products, electrical power cannot be stored in large amounts and transmitted to the consumers when they have additional needs for it. For this reason, electrical power generation should have available those capacities of generating installations and electrical networks which provide uninterrupted electrical power service to consumers. It is natural that the electrical power stations or even groups of them which operate in isolation, and which are connected together by electrical networks, but which do not have reliable intergroup electrical connecting links of the requisite carrying capacity, cannot render mutual assistance in emergency situations, and as a consequence, cannot provide uninterrupted electrical power service.

This situation also applies for centralized heat supply, however, the scales of the combining in this case are limited to the region which is supplied with thermal power from several TETs's [heat and electric power stations] or boiler facilities.

As electrical power supply practice in the U.S. has shown, the lack of requisite electrical links between power systems can have severe consequences. Thus, in the period 1965 to 1977, there were repeated emergencies in the U.S. on the electrical power networks with long term disconnections of consumers. The emergency in the middle of July in 1977 was especially severe as a result of which, New York, a city with a population of several million, was deprived of electrical power for 25 hours.

An advantage of large scale power systems over decentralized generating sources or their local associations should also be considered in another extremely important sense. With an increase in the scale of power combination, its operational efficiency increases and the possibility of more efficient expenditure of the primary energy resources is assured. This is achieved through the centralization of energy supply and the maximum concentration of energy production, which permit an increase in the per unit capacities of the power equipment and generating sources as a whole.

The principle of centralization of the power supply and the concentration of power equipment of large unit capacities in large scale generating sources, which was provided in the Leninist GOELRO [State Commission for the Electrification of Russia (1920)] plan, has been taken as the basis for the development of power systems in the USSR.

To assure a reliable and high efficiency energy supply to the national economy, electrical power engineering should be based on the comprehensive utilization of scientific and engineering achievements.

The major problems which should be resolved by modern power systems can be reduced to the following:

--Total and reliable supply of electrical power to all sectors of the national economy (industry, transportation, agriculture, municipal and domestic loads, etc.) at the requisite level of quality (in terms of voltage and frequency);

--Providing thermal energy (steam and hot water) for production process requirements and for the needs of the municipal and domestic sector;

--The generation of electrical and thermal power at minimum production cost, something which is achieved primarily with their combined generation at a TETs.

The normal operation of a power system and all of the components incorporated in it is assured by observing the following rules and organizational stipulations:

--Combining all of the generating sources with a single electrical coupling link, something which assures synchronous operation between the individual sets and all of the electric power stations included in a power system;

--Parallel operation of electric power stations into common electrical networks should be provided through durable and high capacity electrical coupling systems. The violation of this rule entails the disruption of the operational conditions and as a consequence, a loss of organization in the power supply to consumers;

--Two types of back-ups should be provided in power systems: mobile, to cover fluctuations in current demands (the peak portion of the load schedule in a 24 hour period) and a common back-up to replace equipment taken out for repairs, covering seasonal loads, as well as to meet additional demands for electrical and thermal power which consumers have (planned);

--Operationally timely (dispatcher) control of the operation of all power generation and electrical devices and installations, as well as economic management of electrical power stations and all types of networks should be constantly realized in a power system.

--The development of power systems has taken place in stages, starting with the setting up of parallel operation of individual sets, through the stage of combining electrical power stations and individual power systems together to the creation of the Unified Power System of the USSR (YeES SSSR).

7.2. The Formation of the Unified Power System of the European Area of the USSR

Soviet electrical power engineering advanced to third place in the world after the U.S. and Germany in terms of the capacity of electric power stations and electrical power generation in a short period of time (1918--1941).

By 1941, the power of all the of the nation's power stations exceeded 11 million KW, and in 1940, more than 48 billion KWH of electrical power was generated.

By this same time period, power systems were in service in Moscow, Leningrad, in the Donbass and Urals, in the Pridnetrov'ye and Povolzh'ye. The power base of the union republics of Azerbaijan, Georgia and Armenia was considerably strengthened in accordance with the GOELRO plan. Water storage and thermal electric power stations were constructed in the republics of Central Asia. New electrical power stations were also constructed in other regions, where industry was developing: in Magnitogorsk, Kuznetsk and in a number of the economic regions of Siberia.

The major feature of the development of power engineering during this period consisted in the fact that along with the construction of power stations, there was a planned construction of power transmission lines. With the construction of a new electric power station, the state plan provided for its connection to existing power facilities.

The combining of electric power stations into power systems was accompanied by the creation of organizational (management) and dispatcher control (operational) administrations on a solidly based structure. Such a control system was implemented for the first time in the USSR.

Power engineering for such large industrial centers as Moscow, Leningrad, the Urals, the Donbass and Pridneprov'ye has developed especially rapidly.

Large thermal power stations, the Kashirskaya using Podmoskovnyy coal and the Shaturskaya using peat were in operation by 1941 in the nation's oldest power system, the Moscow power system; one of the largest heat and electric power stations in the nation was placed in service, the Novomoskovskaya GRES using hydrogenous Podmoskovnyy coal, and had a capacity of 350 MW. Turbine sets with a capacity of 50 MW each and one with a capacity of 100 MW were installed at this electric power station. Thermal condensation of electric power stations, arranged about the periphery were incorporated in the Moscow power system; double 110--220 KV electric power transmission lines ran from these stations to feed power to the main large substations (the Izmaylovskaya, Kozzhukhovskaya, etc.). Several central heat and electric power stations also operated in the system (TETs's Nos. 8, 9, 11, 12 and the motor vehicle plant TETs), which were located in different regions of Moscow. Each TETs was coupled to 110 or 220 KV electric power networks, while a portion of the electrical power was transmitted to the municipal cable network at the generator voltage.

The nation's second largest power system before the war was the Urals power system, which combined electric power stations at a distance of 1,000 km from Solikamsk in the north to Magnitogorsk in the south. The Urals system actually consisted of three power regions: in the north, in the Perm' economic region where the Kizelovskaya GRES, the Zakamskaya and the Bereznikovskaya TETs's were in service; and in the Central Urals in the Sverdlovsk region, where the Yegorshinskaya and Sredne-Ural'skaya GRES's and the Nizhnetagil'sk Plant TETs were operating. The electric power station of the Magnitogorsk metallurgical plant and the Chelyabinsk TET's and GRES were the largest power stations in the Southern Urals, in the Chelyabinsk region. All three power regions of the Urals were joined together by 110 KV power transmission lines. Since 110 KV lines with an overall length of more than 1,000 km could not serve as a solid framework for a power system, the strengthening of the electrical coupling networks was planned through the construction of 220 KV power transmission lines, something which was accomplished during the war time period.

The Leningrad power system, just as the Moscow system, was started in the first years of the implementation of the GOELRO plan. The Volkhovskaya GES was the first placed in service. The power from the Volkhovskaya GES was transmitted to Leningrad via 110 KV electric power transmission line. The "Utkina Zavod'", renamed the "Krasnyy Oktyabr'" GRES, thermal electric power station was constructed at a peat deposit, likewise in accordance with the GOELRO plan , and this station was also coupled to Leningrad by a 110 KV line. The Svirskaya GES was placed in service in 1933, from which electrical power was fed to the power system via 220 KV transmission lines, while the powerful Dubrovskaya GRES using peat was also constructed later.

The Donbass power system, which provided power for an extremely rich coal and metallurgical complex, rapidly developed in the nation's south. A provision was made in the GOELRO plant for the priority construction of the Shterovskaya thermal electric power station, which placed in service in 1926. The Shterovskaya GRES operated on a local fuel: anthracite coal dust. The largest electric power station of the Donbass power system was the Zuyevskaya GRES, which was located in the center of the system. The Zuyevskaya GRES, which was equipped with turbine sets with a capacity of 50 MW each and one 100 MW set, which were large for that time, was, along with the Novomoskovskaya GRES, one of the most powerful thermal electric power stations in the nation. The Donbass power system had a branched electrical power network, consisting of 22, 35 and 110 KV power transmission lines.

The Dneprovskaya power system underwent a great expansion following the placement of the Dneproges with a capacity of 560 MW in service in 1932. In addition to Dneproges, the Dneprodzerzhinskaya and Krivcrzhskaya TES's using Donetsk coal were also operating in the power system. The Dneprovskaya power system was the only one in the nation which developed using a network voltage of 154 KV.

Power systems were also created in the prewar years in three Transcausasus Union Republics. The Azerbaijan power system developed especially rapidly because of the creation of oil fields, as well as enterprises for oil refining and chemical plants. The Azerbaijan power system was based on the developed 35 KV power network and 110 KV lines. Two other Transcaucasus systems, the Georgian and Armenian, were based entirely on hydroelectric power stations. The basis for the Georgian system was the Zemoavchal'skaya GES on the Kura River. Small capacity hydroelectric power stations constructed on the Zanga River were in service in the Armenian power system.

The most developed power system in Central Asia was the Uzbek system, which included hydroelectric power stations on the Chirchik River and the small Ferganskaya TES.

The most developed power system in the Povolzh'ye was the Volgograd system, created on the basis of the thermal electric power station of the same name.

The power system in Khar'kov was formed on the basis of the municipal condensation thermal electric power station (ESKhAR) and the tractor plant TETs. Electrical power was transmitted from the ESKhAR via a 110 KV line to the main electric power network at a voltage of 35 KV and the municipal cable network at a voltage of 3 to 6 KV.

The Azov-Black Sea power system (Azcherenergo) with the center at Rostov-na-Don had approximately the same structure. Here, besides the small municipal TETs, some rather large thermal electric power stations were in service: the Shakhtinskaya GRES and the Combine No 100 TETs, which ran on Donetsk pulverized coal. These two thermal electric power stations were tied to the Rostov electrical power network by 110 KV transmission lines. The electrical power was distributed in the networks at a voltage of 35 KV and in the city by 3 to 6 KV cables.

The Novosibirsk power system was formed by the end of 1940. By this time, the large Novosibirsk thermal electric power station using Kuznetsk coals and having sets with a capacity of 25 MW each had been placed in service.

On the eve of the Great Fatherland War, an important combining of several power systems took place in power engineering; thus, in May of 1940, a 220 KV line went into service, which combined the Dneprovskaya and Donbass power systems. This line started in the Zaporozh'ye region from the Dnepr-Donbass 220/154 KV substation and terminated at the Kurakhovskaya GRES substation of the Donbass power administration.

The Kurakhovskaya thermal electric station with sets having a capacity of 50 MW each was likewise brought on line on the eve of the war and was the coupling link between the two power systems.

At the end of 1941, in the severe winter which was difficult for the nation, after the Uglichskaya and Rybinskaya GES's on the Volgo were brought on line, the Yroslavskaya, Ivanskaya and Gor'kovskaya power systems were combined on one hand via power transmission lines, and on the other, via a two circuit power transmission line at 220 KV to the Moscow power system.

The Great Fatherland War slowed the process of combining power systems for several years, however, the successful experiment with combining power systems served as a solid foundation for the further expansion of work in this field.

The war did enormous damage to power engineering and electrification in the nation, and set it back tens of years. The power capacities of the largest power systems outfitted with first rate equipment, the Moscow, Leningrad, Donbass and Volgograd systems, were completely or partially lost. The electrical networks suffered greatly: during the period of the war, more than 10,000 power transmission lines at a voltage 10 KV and higher were destroyed, which amounted to 45 percent of their overall length. Turbines, generators, transformers, electric motors, pumps and other equipment were disassembled and transported from areas near the front. Plants and factories were evacuated to the Urals, to Siberia and Central Asia. The question of providing them with electrical power came to the fore in all its severity. The most serious situation with electrical power supply occurred in the Urals, the power system of which was not designed to cover the additional loads, and the main thing, did not have branched electrical networks.

As has already been indicated, the Urals system had electrical power transmission lines at 110 KV which were inadequate in terms of carrying capacity. During the wartime years (1941-1944), the capacity of the Urals power system doubled, and by the end of the war, this power system had become the largest. An especially large amount of work was done to expand electrical networks. By the end of 1945, the length of power transmission lines at voltages of 35 - 110 reached 3,687 km, and the capacity of step-down substations amounted to 1,000,000 KVA.

A number of steps were taken to boost the reliability of the Urals power system: forced excitation of the generators, the installation of fast acting relay protection; devices for relieving the load on the system with a drop in the frequency were especially effective. As a reuslt of all of the indicated measures, in conjunction with a strengthening of the carrying capacity of power transmission lines, the number of breakdowns with a disruption of reliable service fell off in one year from 33 (1943) to 2 in 1944. There were no such emergencies in the following year.

The increased capacity of the Urals system and the complexity of power supply to consumers necessitated an organizational realignment; the system was broken down into three independent systems: the Sverdlovsk, the Chelyabinsk and Perm' in accordance with the administrative breakdown.

A main administration, Glavuralenergo and a combined dispatcher control administration, the ODU of the Urals, were formed to strengthen economic and operational management under the new conditions.

Thus, a number of measures were implemented under the complex wartime conditions to refine the system for power engineering management.

During the period 1941--1945, six new power systems were formed in the nation's east and north.

Power systems were formed in Omsk, Tomsk, Krasnoyarsk, Ufa, Barnaul and Orenburg based on municipal or plant electric power stations and electric networks at a voltage of 35 KV. Work was done in these power systems to expand the existing and new, partially built thermal electric power stations for the purpose of meeting the rapidly rising demands for electrical and thermal power. Electric power transmission lines at 35--110 KV were constructed to improve the flexibility and reliability of the electrical power supply. The municipal 3 to 6 KV cable networks were significantly expanded.

New power capacities were introduced and the length of electric power transmission lines at all voltages was significantly increased in the existing power systems during the war years: Novosibirsk, Kuzbassk, Karagandinskaya, Altay and Uzbek power systems. During the same period, work continued on building power capacities in the Kuybyshev, Saratov and Kazan power system, as well as in the Transcaucasus republics.

Because of the blockade of Leningrad, the power balance of the city became extremely bad. A cable was run along the bottom of Lake Ladoga to feed electrical power from the Volkhovskaya GES to the besieged city. The execution of this measure was a contribution of inestimable value to the overall defense of Leningrad.

The restoration of the power systems destroyed in the course of the war in the Moscow power system began after the rout of German troups at the end of 1941. The disassembled equipment was returned and once again installed at the Kashirskaya, Shaturskaya and other electric power stations. The restoration work expanded on a wide scale beginning in 1943 after the liberation of the Northern Caucasus, Volgograd, Rostov-na-Donu, Khar'kov and the Donbass. In the course of three years, 1942-1945, the activity of the Donbassenergo, Khar'kovenergo, Rostovenergo power systems and a number of others was restored.

In 1945, the total length of electrical power transmission lines at voltages of 10 to 220 KV increased up to 23,803 km throughout the entire nation. By the end of the war, restoration work was underway throughout the entire territory of the Soviet Union, and the power systems were restored in all of the economic regions and industrial centers of the nation.

In terms of installed capacity of electric power stations, the prewar level was reached in 1945, and in terms of electrical power generation, in 1946. As a result of a performance of a large volume of work to renew old and construct new electric power stations, their total capacity increased by 75 percent by the end of 1950, while the electrical power generated in this year increased by 90 percent as compared to prewar 1940.

The power systems of the Tsentr were combined from 1946 to 1950. In 1950, the power of this power system combination exceeded 2.8 million KW, while the electrical power generation amounted to 16.3 billion KWH. During this same period, the Yug [South] combined power system also underwent further development. In 1956, after the Volzhskaya GES imeni V.I. Lenin with a capacity of 2.3 million KW and the 400 (500) KV electric power transmission line which had been constructed from it to Moscow went into service, the prerequisites were created for the formation of the YeYeES [unified power system of the European area of the USSR].

A 500 KV power transmission line was constructed in 1958 from the Volzhskaya GES imeni V.I. Lenin to the Urals and the combined Urals power system became a component part of the YeYeES.

In 1959, with the completion of the construction of the Volzhskaya GES imeni 22nd CPSU Congress with a capacity of 2.53 million KW and the 500 KV power transmission line to Moscow, the above GES and the Voronezh power system were connected to the YeYeES.

In 1965, the YeYeES had then combined 43 power systems and 4 power regions with an overall electrical power station capacity of 54 million KW; the maximum load on this system reached 45 million KW. During 1965, all of the YeYeES electric power stations generated 292 billion KWH, a figure which comprised 58 percent of all of the nation's generated electric power. A 330 KV power transmission line was constructed from the Kalinin power system to Leningrad at the beginning of 1966. When it was placed in service, the powerful combined Northwest power system was connected to the YeYeES, where this system encompasses seven power systems: Lenergo, Kalingradenergo, Karelenergo in the north, three Baltic power systems (Estonergo, Latvenergo and Litovenergo), as well as Belorussenergo in the nation's west. The connection of these power systems increased the overall capacity of the YeYeES up to 65 million KW.

The formation of the Unified Power System of the European Area of the Nation basically occurred in 1970 following the connection of the Transcaucasus combined power system to it (Azenergo, Gruzenergo and Armenenergo).

The process of combining power systems also occurred in Siberia, Central Asia, in the Far East and in northern Kazakhstan.

A total of 63 power systems were combined in the YeYeES, the OES [combined power system] of Siberia and the OES of Central Asia. In 1970, the installed capacity of YeYeES electric power stations amounted to 104.9 million KW, while the electric power generated was 529.6 billion KWH. The OES of northern Kazakhstan and individual energy regions of Western Siberia were incorporated in the YeYeES in 1972. This combined power association has been given a new name: the Unified Power System of the USSR (YeES USSR).

7.3. The Development of the Unified Power System of the USSR

The development of the YeES of the USSR continued in the Ninth Five-Year Plan through the construction of newelectric power stations and networks, as well as the connection of new power systems and power regions. The overall installed capacity of the electric power stations incorporated in the combined power systems amounted to 198 million KW at the beginning of 1976 (90 percent of the entire installed capacity), while the electrical power generated reached about 95 percent of the overall power generation in the nation. The installed capacity in the YeES of the USSR at this time amounted to 153.0 million KW (including 131.2 million KW at TES's and AES's, and 21.8 million KW at GES's), while the electrical power generation reached 781.0 billion KWH (78.5 percent of that generated by all of the nation's OES's).

The northern Kazakhstan OES was included in the YeES of the USSR during the years of the Ninth Five-Year Plan, and the Far East OES was created (incorporating the Amur, Khabarovsk and Primorskaya power systems). A number of power regions and power systems have been tied together for parallel operation: the Chitinskaya with the Siberian OES, the Kol'skaya with the Northwest OES, the Turkmenskaya with the Central Asian OES, the Surgut power region with the Urals OES, the Kzyl-Ordinskiy with the Central Asian OES and the Astrakhan with the Tsentr OES.

Since 1973, the Bulgarian power system has operated in parallel with the YeES of the USSR, the connection to which is made via the international electrical power transmission system at a voltage of 400 KV: the Moldavskaya GRES----Vulkaneshty--Dobrudzha.

The combining of the power systems with each other produces a significant economic impact. Thus, by virtue of the intersystem effect in the YeES of the USSR, the power demand to cover the load maximum has been reduced by 4.5 million KW.

7.4. Control of the Combined Power Systems

In contrast to discrete production operations of the majority of the sectors of the national economy, a special form of operational management has developed in power engineering with its continuous technological generation and consumption process of electrical power: dispatcher control service for power systems.

The dispatcher services of the Soviet Union power systems have developed an operational style over the long years of their existence which consists in a clear cut and operationally timely manner of supervision, a high degree of discipline and responsibility of personnel for the assignments. A distinctive feature of dispatcher service in our country is the complete responsibility of the dispatcher for the operation of the electric power stations, electric power networks and the power supply to consumers. An order of a dispatcher is law and is unconditionally executed by all links in a power system.

Dispatcher services have undergone great changes over the last decade in capitalist nations because of the influence of the centralized control system used in the USSR. Central dispatcher administrations have been created in the U.S., England, France and in other nations, which perform the functions of coordinating the power systems of different regions of the nation, without interfering in their production activity. However, the dispatcher control administration for the private power associations of the U.S. in this case are rather autonomous organizations. In England and France, where electric power stations and electric power networks have been nationalized, a unified dispatcher service has been created.

A new type of dispatcher service, which follows from the centarlization and planning of power engineering, just as of the economy of the entire nation, was set up in 1925, when the Central Dispatcher Service was organized in the Moscow power system. The Central Dispatcher Station was also created then, where the control facilities for the operation of the electric power stations and the power networks were concentrated.

In 1927, after the Volkhovskaya GES was brought on line, dispatcher service was also organized to control the operation of thermal electric power stations operating in conjunction with the GES.

A comprehensive theory has been developed and enormous experience had been accumulated in centralized dispatcher (operational) control of power engineering over the 50 years which have elapsed since the organization of the first dispatcher service.

Prior to the combining of power systems, dispatcher services were an integral part of the organizational structure for the management of a power system and were correspondingly subordinated to system management.

In 1940, after Donbassenergo was combined with Dneproenergo by a 220 KV power transmission line, a new form was produced: dispatcher service for the associations of the South power system.

Combined dispatcher control of the power systems of the central region (Tsentr ODU [combined dispatcher control]) was formed in 1945, which included the power systems of Moscow, Yaroslavl', Ivanovo and Gor'kiy. The coupling link for these power systems was the Rybinskaya and Uglichskaya hydroelectric power stations.

The scales of power system combining in our country, which were without analogs in world practice, required an exceptional clear-cut and well tuned organizational structure for dispatcher control.

At the present time, the structural organization of the dispatcher service consists of the following links:

The central dispatcher control of the Unified Power System of the USSR (TsDU YeES USSR) and the combined dispatcher control of the European area of the nation (ODU YeES);

The dispatcher controls for the combined power system (ODU OES);

Central dispatcher stations of out systems (TsDP ES).

The dispatcher control system is complemented by the operational control services for electric power stations and networks.

A central control console (panel) exists at all electric power stations, from which the on-duty engineering controls the equipment operation.

Operational control in electric power networks is concentrated in the dispatcher stations of the electrical power network enterprise, the DP PES, and the dispatcher stations of regional electric power networks (DP RES) are subordinate to the dispatcher of the DP PES.

In an operational sense, the control personnel of an electric power station (the on-duty engineer) and an electrical network enterprise are subordinate to the power system dispatcher.

The centralized dispatcher control system for power generation management should not only provide for continuous covering of the demand for electrical and thermal power, but also keep track of the economic indicators of the operation of electric power stations, electric networks and electric power systems as a whole, since the economic indicators when power systems are combined are not governed solely by the operating economy of the sets and electric power stations.

In combining electric power stations which differ in terms of the economic indicators and the nature of power generation, power systems can have an impact on the shaping of the average energy production cost for a system through their own dispatcher services. The distribution of loads among individual electric power stations by the hour, by the day, by the month and by the seasons of the year can, with a skillful management of the operation, reduce the expenditures for generation, curtail the overall and specific consumption of fuel, or in the case of incorrect organization, degrade the technical and economic indicators of a power association.

The question of the correct and economically advantageous distribution of loads is becoming an increasingly acute one in the Unified Power System of the USSR.

The deviations in the production cost in individual power systems from its average value for the nation as a whole, including that with respect to systems tied together by common power transmission lines, are quite considerable, since the production cost is influenced by the cost of fuel, the percentage of cheap electrical power generated by hydroelectric power stations and the equipment complement.

Thus, the production cost of energy in the Donbass power system, which has only thermal electric power stations, is significantly higher than for the adjacent Dneprovskaya, which includes large hydroelectric power stations. For this reason, the problem of the economically expedient distribution of loads between sets within each electric power station, between electric power stations within a power system, and finally, between combined power systems of a unified electric power network is an urgent one for the dispatcher service.

One of the factors in optimizing dispatcher control is the more complete loading of the installed capacity of economically efficient power stations in the USSR.

The dynamics of the change in the number of hours of utilization of the average annual installed capacity of the electric power stations of the USSR Ministry of Energy are shown in Table 7.1. As can be seen, over the course of 15 years, the number of hours of capacity utilization remains practically constant and characterizes a high level of loading of the power generation equipment. The utilization of the capacity of thermal electric power stations is somewhat above the average level. On the other hand, the utilization of the capacity of hydroelectric power stations is significantly less than the average load. This is explained by the fact that the dispatcher control for power systems utilizes the power of GES's primarily to cover the peak portion of the load schedules of power systems.

The fuel component of the electrical power generated by thermal electrical power stations exerts the decisive influence on the average weighted production cost of electrical power in power systems. The specific weight of thermal electrical power stations in the overall capacity of the entire nation's electrical power stations exceeds 80%, while the fuel component in the production cost of the energy they produce reaches 70%. This is of special significance in the optimization of the loading of thermal electrical power stations, which on one hand have equipment with different parameters and correspondingly, different efficiences, and on the other hand, use numerous kinds of fuel with different costs.

Table 7.1. The Number of Hours of Utilization of the Average Annual Installed Capacity of Electrical Power Stations

Electric Power Stations	1960	1965	1970	1975
Thermal stations, including power stations	6,013	5,803	5,423	5,741
Water powered	3,855	3,780	4,146	3,354
All electric power stations	5,377	5,288	5,136	5,257

The most important economic indicator of the operation of thermal electric power stations is the specific fuel consumption for the generation of 1 KWH of electrical power and 1 GCal of heat which is usefully delivered to the consumer. It is well known that the boiler equipment of electrical power stations has the most advantageous operational modes at loads of 85 to 90 percent of the nominal; with an increase or decrease in the loading, there is a degradation of the technical economic indicators and an increase in the specific fuel consumption and consumption of electrical power for internal needs.

With a rise in the loads, the dispatcher should first load that electrical power station which has a high efficiency and the lowest specific fuel consumption. A thermal electrical power station having a small specific fuel consumption should be fully loaded, although it is possible in this case that its own efficiency will be degraded, and vice versa, an electrical power station having a specific fuel consumption should bear the minimal load, although this likewise entails a degredation of its technical and economic indicators. This examples shows that noneconomical and disadvantageous operational modes can be specified for an individual electrical power station.

As early as 1927, the distribution of loads between electrical power stations operating in parallel was worked out in the USSR in accordance with their technical and economic data. According to this theory, the most favorable distribution among the individual electric power stations and sets should be based on the method of relative increments in heat consumption. In line with this method, system economy for sets operating in parallel increases when the load is transfered to the set which had the least relative increase in expenditures, even in the case where this set can have the lowest efficiency.

A trend which is permanently in place in Soviet thermal power engineering is the reduction in the nationwide average indicators for specific fuel consumption per generated KWH of power and GCal of heat; this is the result of implementation of a complex of measures: the introduction of high pressure installations, the transition to power units of a large unit capacity, the construction of central heat and electric power generating stations with their high efficiencies, and finally, the economically substantiated utilization of the capacities of thermal electrical power stations.

Over the last decade (1965-1975), the specific consumption of conventional fuel for the generation of electrical power has been curtailed by 73.5 grams per KWH of output. The total over the 10 years for the overall savings in fuel amounted to 280.4 million tons figured in conventional terms (7,000 KCal/kg).

Data on the reduction in the specific consumption and saving of fuel at the thermal electrical power stations of the USSR Ministry of Energy over the last 10 years are given in Table 7.2. In having achieved a level of specific fuel consumption of 340.1 grams per KWH of output, the thermal electrical power stations took the lead ahead of U.S. electrical power stations and went to first place in the world.

Along with the increase in the number of hours of utilization of the average annual installed capacity of electrical power stations and the reduction in the specific fuel consumption, power associations also permit the following:

--An increase in the unit capacity of generation sets;

--A reduction in standby capacities;

--A reduction in the installed capacities since the maxima of the electrical loads in power regions located at different latitudes do not coincide.

Examples are given below which illustrate the three factors indicated above.

Working from economic prerequisites, which are determined by the necessity of having a backup capacity in a power system with the shutdown of the highest power set, as well as the conditions for the stability of the power system with the emergency disconnecting of a generator, the unit capacity of a set should not be more than 15 percent of the capacity of the power system.

In 1958, when the capacity of the Moscow power system was increased, and additionally, the Kuybyshev-Moscow power transmission line was constructed, it became possible to install four units fo 150 MW each at the Cherepetskaya GRES. Thus, the increase in the capacity of the power generation systems, the parameters of the electrical power transmission line and the implementation of measures to maintain the system stability have made it possible to increase the unit capacities of sets and power stations. Over the last 10 to 15 years, 11 combined power systems have been formed in the nation. The major indicators of these combined power systems during 1975 are given in Table 7.3.

As follows from the data of Table 7.3, the nature of the load on combined power systems differs somewhat among the systems. Thus, while in the Tsentr OES the load maximum amounted to almost 97.3 percent of the installed capacity, in the South OES, the load maximum is 77.7 percent. The Urals OES also has a high load on the capacity of the electric power stations, amounting to 84.0 percent.

The connection of the Urals OES via a 500 KV power transmission line to the Tsentr OES through the Volzhskaya GES imeni V.I. Lenin has made it possible to reduce the design figure for the power demand to cover the peak portion of the load schedule in combined power systems by approximately 500 MW.

The great reduction in the power demand with the combining of Tsentr and the Urals is explained by the difference in the time zones. In the Urals zone, the morning and evening load maxima begin two hours earlier than in the Moscow zone. Under these conditions, the power of the Volzhskaya GES imeni V.I. Lenin is first routed to the Urals, and then in step with the drop there in the load maximum, is routed to Tsentr to cover the increasing load in this region.

This circumstance is particularly clearly pronounced in the creation of the YeYeES (a schematic map of 330 KV and higher voltage electrical networks in 1975 is found on the fly-leaf at the beginning of the book). In 1967, with the work on the creation of the YeYeES still uncompleted, the combined maximum of the entire system (Tsentr, Urals, Northwest, South, Central Volga and Northern

Table 7.2

The Reduction in the Specific Consumption of Conventional Fuel and the Savings in Fuel in the Generation of Electrical Power Over the Period From 1965 Through 1975 at Thermal Electrical Power Stations of the USSR Ministry of Energy

Годы Years	(1) Отпуск электроэнергии, млрд. кВт·ч	(2) Удельный расход условного топлива, г/(кВт·ч)	(3) Снижение удельного расхода по сравнению с 1965 г., г/(кВт·ч)	(4) Экономия топлива по сравнению с 1965 г., млн. т
1965		413,6		
1966	359,7	403,7	9,9	3,6
1967	403,7	392,9	20,7	8,4
1968	435,7	384,3	29,3	12,8
1969	473,3	376,4	37,2	17,6
1970	515,0	366,3	47,3	24,4
1971	568,8	359,0	54,6	31,1
1972	605,2	354,0	59,6	36,1
1973	654,1	348,0	65,6	42,9
1974	694,5	344,4	69,2	48,1
1975	753,5	340,1	73,5	55,4
		Всего за 10 лет Total over 10 years		280,4

Key: 1. Electrical power output, billions of KWH;
2. Specific consumption of conventional fuel, g/KWH;
3. The reduction in the specific consumption as compared to 1965, g/KWH;
4. The fuel savings as compared to 1965, millions of tons.

Caucasus) amounted to 62.3 million KW, while the sum of the maxima of the individual power systems (with their onset at different times of the day) was equal to 64.5 million KW, i.e., 2.2 million kilowatts greater.

Consequently, in the case of separate operation of the power systems, it would have been necessary to have almost 2.5 million KW in addition, which is about 4 percent of the entire capacity of the electric power stations.

With the combining of the power systems, it becomes possible to curtail the standby capacities. It is well known that the temporary loss of capacity, for which the standby serves to compensate, cannot occur simultaneously in all power systems or electric power stations included in the combined association. Consequently, the overall standby capacity, determined in the case of separate operation of the power systems, can be reduced down to a reasonable level. The amount of the reduction in the standby capacity with the combining of power systems depends on several factors: on the power transmission junction lines and

Table 7.3

The Main Indicators for the Combined Power Systems of the USSR During 1975

Combined Power Systems	Installed Electrical Power Station Capacity, 10^6 KW	Electrical Power Generated, 10^9 KWH	Winter Load Maximum, 10^6 KW
Tsentr	29.8	156.1	29.1
Central Volga	12.7	60.8	10.6
Urals	25.4	148.8	21.4
Northwest	32.0	96.0	15.8
South	38.4	206.3	29.9
Northern Caucasus	8.4	38.9	6.8
Transcaucasus	8.0	35.3	5.9
Kazakhstan	7.2	38.8	6.0
Total for the unified power systems of the USSR	152.9	781.0	125.5
Siberia	27.3	140.1	21.3
Central Asia	11.7	49.6	7.8
East	5.9	23.3	4.5
Overall for the combined power systems	197.8	994.0	-

their carrying capacity, the specific ratio between thermal and water powered electric power stations, the decisions made as regards the forcing of the setting of the loads, etc.

The processes in electrical power supply which take place rapidly require flexibility in the standby capacities for power systems. Hydroelectric sets have great flexibility in terms of coming on line and setting loads. The size of the "hot" standby depends on the ratio of the capacities in the system between the thermal and water powered electric power stations. Where high power hydroelectric power stations are present and they have a large specific weight in a power system, the system reserve can be reduced by curtailing the "hot" standby of thermal power stations.

Thus, combining the Donbass power system with the Dneprovskaya system made it possible to reduce the design figure for the overall standby capacity by approximately 200 MW.

As operational experience with power systems and their combinations has demonstrated, the overall standby capacity for the generating devices should be no less than 13 percent of the entire system capacity.

7.5. The Technical Means of Controlling Power Systems

The combining of power systems into the unified power system of the nation poses the problem of dispatcher control in a new manner.

The existing engineering tools cannot assure an optimal design of the operational modes or the maintenance of the static and dynamic operational stability of combined power systems.

The diversity of the generating sources, which have different technical characteristics, as well as the sophisticated electrical network with power transmission lines in parallel and which overlap in terms of voltage require a large volume of calculation in the determination of the operational modes of power systems on a daily, weekly, monthly and seasonal basis.

The increased volume of calculation work becomes beyond the ability of the operational services. In the final analysis, the workers of the operational services are forced to make the mode calculations for power systems using global indicators, relying on their own rich experience and engineering intuition.

The stability of power systems, and as a consequence of this, the reliability of the power supply to consumers can be improved through the use of various means: sensitive relay protection, automatic frequency regulators, automatic repeat connection devices, and systems for forced excitation of generators.

The operational reliability of combined power systems is assurred by a combination of an efficient operating mode, determined by the dispatcher service and a system of counter emergency automation, the purpose of which is to automatically relieve the load on intersystem links.

Counteremergency automation, under operational conditions where power shortfalls or deficiencies occur which were poorly taken into account by the operating service or which occur suddenly in one or more power systems incorporated in an OES, should protect the turbines of thermal and water powered electric power stations against overloading and disconnect a portion of the load in case it is necessary.

The automatic load disconnect devices are set up in the YeES of the USSR to disconnect approximately 5 percent of the system capacity in emergency situations.

Automatic repeat connection devices have become widespread in the USSR: at the present time, more than 100,000 of the devices which act for both three-phase and single phase disconnections have been installed in 6 to 500 KV electrical power networks.

Several hundreds of fast response repeat connection devices with a connection pause of up to 0.6 sec have been installed the electrical power networks. Repeat connection devices have been designed and introduced which are capable of capturing synchronization, i.e., repeatedly and synchronously connecting the disconnected line.

Since practice has shown that one-time repeat connections do not always achieve the goal, for example, in the case of a stable short circuit, three-phase multiple connection units have been designed, and the overall number of them exceeded 6,500 units by the beginning of 1976.

Automatic load relief devices are extremely effective in providing for operational stability of power systems with a drop in the frequency, the number of which exceeds 6,700 units. Automatic standby connection devices are of great importance in combined power systems. Almost 47,000 such units have been introduced in power engineering. So-called frequency start-up devices for hydroelectric generators will likewise serve for automatically starting a set from standby in the case of a drop in the frequency. Some 164 such devices have been installed.

Automatic standby switch-in and frequency start-up devices for hydroelectric generators facilitate the work of on-duty personnel at electric power stations and dispatcher stations, giving them the time to take other indispensable and operationally steps when emergency situations arise.

In the power systems of other countries, only several years after the large intersystem accident in the U.S. were steps taken to introduce strong frequency load relief regulators and other counteremergency measures.

The power systems of the Soviet Union are constantly improving the economic indicators for fuel utilization.

Great importance has always been attributed to the operational service of power systems: the overall system economic indicators depend on the precision of the calculations of this service. A theory was developed in the Soviet Union for the distribution of loads among power generation units having different technical and economic characteristics. However, the growth in the capacities of electric power stations and power systems, the planning, and especially the regulation of loads becomes a complex problem for dispatcher services.

The only possible way of solving this problem consists in a systemic approach and an optimization of planning for the utilization of power equipment and the operation of power systems. To achieve this goal, it is essential to equip the operation services with economic and mathematical models of power systems, as well as with algorithms and programs for their calculations. Mathematical modeling, and the voluminous calculations related to them can be executed using modern computer equipment.

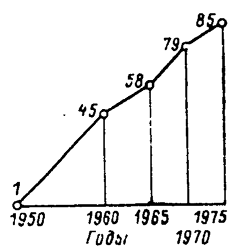

Figure 7.1. The number of remote controlled dispatcher stations of power systems.

A certain amount of experience has been acquired in the field of utilization of new technical tools for the control of power systems in the Soviet Union. Specifically, remote control for dispatcher stations has become quite widespread. Work in this direction was started as early as the 1950's. In the 10th Five-Year Plan, some 85 power systems in all will be equipped with remote control facilities. The dynamics of the introduction of remote controlled devices for power systems is shown in Figure 7.1.

During the Ninth Five-Year Plan, more sophisticated automated control systems using electronic computers have been created in the power system of the USSR. These automatic systems vary in terms of the level of the problems which can be solved and the technical tools, and obsolete or insufficiently fast computers are used in them. Along with this, the existing ASU's [automated control system] for power engineering make it possible, first of all, to acquire experience in the utilization of computers in the control processes of power systems, and secondly, to train personnel for working with moresophisticated and powerful computers.

It is necessary to solve the following main problems to automate the control of power systems at their present stage of development:

--Establish a clear-cut interrelated hierarchical control structure for all links: from the lowest stages (set, electrical power station) to the dispatcher and economic planning level;

--Determine the technical means of control and planning, taking technical and program compatability as the basis for them;

--Work out a unified system of program software based on standard algorithms and routines;

--Compile the program and implement on this basis the design of the data file which is capable of providing information for ASU's at all levels of power engineering.

The initial or lowest step on the hierarchical ladder of the power engineering ASU is the automatic control systems for power generation sets, units and power networks (transmission lines). The most important and complex units are the ASU's for thermal and nuclear electric power stations (Figure 7.2) [not reproduced]. In 1976, ASU TP's [automated control systems for technological processes] were introduced at the Zmiyevskaya, Burshtynskaya and Moldavskaya

TES's. The economic efficiency of the ASU TP's is still inadequate and the investment payback period amounts to 1.8 to 3 years (the average payback period for ASU TP's as a whole for the industry amounts to 1 to 1.5 years).

ASU TP's are being introduced at hydroelectric power stations to solve problems of operational production process control: regulation of the power, voltage, frequency and optimization of operating modes within the stations.

The Ust'-Ilimskaya and Krasnoyarsk GES ASU TP's are designed to improve control quality and operational timeliness, operational reliability of the equipment, and produce the best utilization of the material and labor resources of the stations.

ASU TP's have also been introduced at the Votkinskaya and Saratovskaya GES's.

A factor delaying the automation of thermal power units is the fact that not all of the auxiliary mechanisms (control and cutoff fittings, coal dust feeders, fuel oil injectors, diverse measurement devices, etc.) of the power units are adapted for shifting them over to automatic control.

In the current five-year plan, it is planned that automated control be implemented for power units at 15 electrical power stations, including power units with a unit capacity of 300, 500, 800 and 1,200 MW. The next step in the automation should be hydroelectric power stations and nuclear electric power stations. As compared to TES's, GES's have simplet equipment and a smaller number of requisite operations to control the equipment (Figure 7.3) [not reproduced]. With the appearance of electronic computers, the possibilities for complete automation of AES's have significantly increased.

It is necessary to design a uniform control system from the set, power unit up to the electrical power station as a whole in the project plan for the comprehensive automation of AES's, GES's and TES. The transition to the system of power units at thermal electrical power stations facilitates the task of comprehensive automation.

To implement comprehensive automation at central heat and electric power stations, it is necessary to develop a system of control algorithms and routines for the heat supplied to industrial enterprises and residential buildings.

Contemporary computer equipment - M-6000, M-7000 and M-400 type all-purpose computers - assure the creation of comprehensive ASU's for electric power stations.

In the design of electric power station comprehensive ASU's, a provision must be made for automatic coupling between the control computers, by means of which the power units will be controlled, and the central computer for the entire electrical power station, the functions of which include the retrieval and processing of the data necessary for the solution of the planning and organizational problems. There can be one or more computers at an electrical power station, depending on the volume of computational work, which in turn, will serve as the coupling links to the computer center of the power system.

The third stage of the hierarchical system for automated control in power engineering is the computer center (VTs) of the power system. The first experiments with the design of a power system computer center were carried out more than 10 years ago in the Donbass power system (in Gorlovka). Second generation computers were used in this system to perform the calculations of the operational modes of the electric power stations and sets for the purpose of loading them in accordance with economical indicators.

The first ASU units were placed in industrial service in six power systems in 1976 in addition to the systems already in service: Litovglavenergo, Estonglavenergo, Gruzglavenergo, Kuzbassenergo, Smolenskenergo and Odessaenergo. As a result, by the beginning of 1977 ASU's for power system based on second generation computers were created in 22 of the largest power systems, the installed capacity of the electrical power stations of which amounted to about 74 percent of the total power of all electrical power stations of the USSR Ministry of Energy. In 1977, ASU's were introduced in six more power systems, and the overall number of power systems encompassed by ASU's grew to 28 at the beginning of 1978.

The economic efficiency indicators of the first ASU stages for power systems can be seen from the following data: the expenditures for the creation were 29.6 million rubles, the annual savings were 13.9 million rubles, the annual economic impact was 4.41 million rubles and the payback period was 1.7 to 2.7 years.

The power system ASU's were placed in service during 1974-1976 have continued to expand, something which is characterized by the growth in the number of tasks being performed.

The number of tasks which had been introduced by the start of 1977 had doubled as compared to 1974.

ASU development occurred not only because of the introduction of new tasks, but also through the expansion of ASU coverage for enterprises (production units), for which the calculations are performed in the computer centers of the power systems.

The power system ASU's in service have had an impact on improving the economic indicators of production. In these power systems, through the optimization of operating modes using computers, expenditures for fuel have been reduced an average of 0.3 percent, and losses in the networks have gone down an average of 3 percent (the relative losses). Thus, in the municipal electrical power networks in Izmail (Odessaenergo), losses in the network have been reduced from 12 percent down to 9 percent with a simultaneous load increase of 9.7 percent.

Considerable work is also being done to improve the basic indicators of production based on the use of computers by Belglavenergo, the Uzbek SSR Ministry of Energy, Azglavenergo and other power systems.

Since operational (dispatcher) control is combined with management control of the ASU's and computer centers in power systems, the power systems should solve an entire complex of problems: the calculation of the operational modes and loads on the equipment, system planning as a whole, operational control, capital construction, as well as material, financial and labor resources.

The selection of the computers and set of peripherals (the size of the external memory, automatic printout, displays, input and output devices, etc.) should be based on a full accounting of the entire volume of data processing for the execution of the tasks presented above. It is necessary to also make a provision in the planning of power system ASU's for devices (multiplexers, modems, adapters) which interface the computers installed at the electrical power stations (the lowest level) to the computers at the dispatcher centers of combined power systems (the upper level). In this case, the interfaces should assure intermachine data exchange in an automatic mode, i.e., provide for direct access to the data files of the lower, intermediate and upper links.

Combined power systems (OES's) are the fourth stage in the hierarchical control system. At the outset of 1977, all combined power systems had ASU's with differing degrees of automation of dispatcher control (Figure 7.4) [not reproduced].

In the 10th Five-Year Plan, it is planned that the operation of the ODU's [integrated dispatcher control] ASU will be expanded by means of bringing on line the second stages, expanding the scope of the tasks to be performed, etc. In the Northwest and Urals ODU, an interesting scheme has been implemented: frequency control by means of small (control) computers.

As was indicated above, dispatcher control ASU's are being created in the OES's, i.e., operational mode and status control. These ASU's do not have functions of economic management, and their programs and data files should be designed to satisfy the needs of the workers in the operational service as well as operational personnel in the dispatcher services. The set of peripherals should also conform to the functions of the computer center, and in particular, a special role is to be played here by displays with a permanent or periodic display of the system status.

Since the dispatcher centers for combined power systems (the South, Central Asia) can be located territorially close to the administrative management organs for power engineering (for example, the ministries of the power engineering of the Ukrainian SSR and the Uzbek SSR) it is expedient to utilize the computer center of the dispatcher station for planning, control and economic management.

A sectoral ASU is being created in the USSR Ministry of Energy, just as in other sectors.

The first stage of the "Energiya" OASU [automated control system for a sector of industry] was placed in service at the end of 1975 with a set of 149 tasks: 17 percent were optimization tasks, 53 percent were accounting, 5 percent were analytical, 10 percent were engineering and 5 percent were the remainder.

The economic efficiency of the first stage of the "Energiya" OASU was: expenditures for the creation of the system were 25.9 million rubles, the annual savings were 10.2 million rubles, the annual economic impact was 1.7 million rubles and the payback period was 2.6 years.

The engineering targets for the design of the second stage were worked out in 1976 and an additional 31 tasks were placed in service.

The "Energiya" OASU services 14 functional subdivisions of the organization of the USSR Ministry of Energy, for which 1,300 calculations are performed annually, and operational calculations using 82 forms are performed daily for two administrations. The overall number of forms completed by the computer is around 600.

In power engineering, because of the uniformity of the production technology for the electrical and thermal power, and the fact that the equipment is of a standard type (in principle) (steam and water powered turbines, AES boilers and reactors, pumps and fans), there are especially favorable conditions for the utilization of standard algorithms and programs. This significantly facilitates the conditions for the design and introduction of ASU's in power engineering. With the standard type technical facilities for automation (a standard series of computers, control computers, and peripherals), standard programs will find wide application in all power engineering control links.

The special significance of the data software for the ASU's and the systematic updating of this data must be underscored. The data fund (or data bank) in power engineering management consists of two components: the permanent and a variable component, more precisely, the continuously changing data. The permanent component of the data bank contains data which do not change or partially change over long periods of time. Included here, for example, is the installed capacity, the parameters of the installations, the plan indicators, etc. The variable portion of the data file consists of the rapidly changing parameters and indicators of the continuous production process. This portion of the data file should be changed (updated) in strict accordance with the change in the loads, the frequency of the systems, as well as the overcurrents of powers and voltages at nodal points in the power network. The variable portion of the data can be assurred when the computers operate in real time and there is a permanently functioning communications system between the computer centers.

The confidence level of data transmission is of especial importance for power engineering ASU's at all levels. The maximum standard for the data transmission confidence level for a given period should be considered as 10^{-7}, i.e., one error per 10 million transmitted characters is permitted. Subsequently, in step with the mastery with new data transmission equipment, the number of errors should be reduced down to 10^{-9}.

In terms of the volumes of functions which can be performed, the most equipment should be supplied to the computer center of the USSR YeES. Here it is expedient to utilize series 1 computer (R-50, R-60), and subsequently, series

2 computers (R-35, 45, 65) with expanded functions, which are capable of solving complex multiple plan problems. Electronic computers at all control levels in power engineering should operate in real time and problems should be solved in program batch processing modes. For the highest stages, it is expedient to organize the work in a time sharing mode.

Automatic and automated systems based on the latest computers lift the operational and organizational planning control up to a level corresponding to the state of the art in equipment and production technology in power engineering.

7.6. The Prospects for the Development of Power Systems

The 25th CPSU Congress defined as one of the major directions for the expansion of power engineering the continuation of work to set up the nation's Unified Power System by means of combining the power systems of Siberia and Central Asia with the USSR YeES. The USSR YeES is a power engineering complex of electrical power stations and networks developing on a national scale, which are combined with a common production process mode with a single operational control, which provides for reliable, economic high quality power supply for the national economy and the populace with the most efficient utilization of the nation's energy resources.

In accordance with the major tasks put foreward by the 25th CPSU Congress, power engineering in the USSR will undergo further development and refinement in the 10th Five-Year Plan. The installed capacity of electric power stations in 1980 will grow up to 276-288 million KW, and it is planned that 1,380 billion KWH will be generated in the last year of the five-year plan in the nation. The specific weight of the installed AES capacity will grow by 1980 up to 6.5 percent of the overall capacity of the electrical power stations. Nuclear power stations with a capacity of 2 to 4 million KW with thermal neutron reactors will be constructed in the current five-year plan. Over the current five-year plan, it is also planned that a large fast neutron reactor will be brought on-line.

It is planned that before the end of the five-year plan, the first power unit with a capacity of 1,200 MW will be introduced at TES. A power block of such unit capacity has significant economic advantages over 300 MW power units: a reduction of 4 percent in the specific fuel consumption. A reduction of 50 percent in the service personnel and 30 percent in the amount of metal used. Modular installations with a unit capacity of 500 to 800 MW will occupy the dominant postion in the new capacities brought on-line at condensation electrical power stations. In 1975, the 500 to 800 MW power unit capacity which was placed in service amounted to 29.4 percent of the overall capacity of thermal electrical power stations, and by 1980, the specific weight of the indicated power units will rise to 48 percent. Heating power units using supercritical steam parameters and having a capacity of 250/300 MW will be installed at TETs's, which supply thermal power for large cities.

At the present time, eight combined power systems (OES's) are incorporated in the USSR YeES: Tsentr, South, Northwest, Central Volga, Northern Caucasus, Transcaucasus, Urals and Kazakhstan. The OES's of Siberia and Central Asia operate separately, and the formation of the East OES is being completed.

Of the nation's 93 power systems, 67 power systems are operating within the complement of the YeES of the USSR, which provide electrical power for the national economy over the territory of the European portion of the nation, the Transcaucasus, the Urals, Northern Kazakhstan and regions of Western Siberia with an overall area of 6.5 million km^2 and a population of about 200 million. The distance between the end points of the territory of the YeES of the USSR amounts to about 3,000 km from north to south, and 4,000 km from east to west. The power of the approximately 1,000 electrical power station operating in parallel in the YeES of the USSR amounts to about 160 million KW and the electrical power output is 839 billion KWH (more than 75 percent of the total output).

Electrical power is exported from the Unified Power System to the Bulgarian People's Republic power system which operates in parallel, as well as to the Hungarian People's Republic, Czechoslovakian SSR, the Polish People's Republic, the German Democratic Republic and Finland.

The bulk of the power capacities of the YeES of the USSR (more than 45 percent) is composed of large thermal condensation power stations with high capacity power units. The Zaporozhskaya and Uglegorskaya GRES with a capacity of 3.6 million KW, which are the largest in Europe, are operating in the YeES, and the capacity of the 18 thermal electrical power stations and two hydroelectric power stations amounts to 2.0 million KW and more. The largest power units with a capacity of 800 MW are installed at the Slavyanskaya (two units), the Zaporozhskaya and Uglegorskaya GRES's (three units each) and 500 MW units are installed at the Troitskaya, Reftinskaya and Nazarovskaya GRES's.

The major hydroelectric power stations in the YeES of the USSR are the Volzhskaya GES's imeni V.I. Lenin with a capacity of 2.3 million KW and imeni 22n CPSU Congress with a capacity of 2.53 million KW. The largest GES's in the world are in service in the Siberian OES: the Bratskaya at 4.45 million KW and the Krasnoyarskaya at 6.0 million KW, while the construction of the Sayano-Shushenskaya GES with a capacity of 6.4 million KW is being completed. Some six nuclear electric power stations with reactor units having capacities of 440 to 1,000 MW are in service in the YeES of the USSR: the Leningradskaya with a capacity of 2 million KW, and the Novovoronezhskaya, Kurskaya, Chernobyl'skaya, Kol'skaya and the Armyanskaya AES's.

Heating power units comprise more than 28 percent of the overall capacity of electrical power stations. Individual TETs's have attained a capacity of more than 0.5 million KW while the largest is the TETs-22 of the Moscow power administration at 1.25 million KW, while the largest heating units have a unit capacity of 250/300 MW.

The power systems included in the USSR YeES are interconnected by networks at voltages of 220-300-500-750 KV. The 220 and 500 KV networks have become widespread in the nation's central and eastern regions. The Tsentr, Central Volga and Urals integrated systems are interconnected by 500 KV lines. In the western and southern portions of the USSR YeES, the basis for the system is the 330 KV electrical power network. Work has been started on the planned reinforcement of the 330 KV network by means of superimposing the next voltage level, 750 KV, on the network. The 750 KV electrical power transmission lines from Donbass to Vinnitsa to the Western Ukraine and Leningrad to Moscow have been constructed.

At the beginning of 1977, the length of 220 KV and higher voltage lines amounted to more than 83,000 km, including 14,800 km at 500 kv and 1,728 km at 750 KV.

During 1976-1980, the USSR Unified Power System will undergo further development (a schematic map of the major electrical networks of the USSR at a voltage of 500 KV and above in 1978 is located in the fly-leaf and end of the book).

After the OES of Siberia is tied in, the territory encompassed by the USSR YeES will grow up to 10 million km^2, with the distance between the end points being 6,000 km and a population of about 220 million. The electrical power generated in the USSR YeES will reach almost 90 percent of the USSR total.

The parallel operation of the USSR YeES with the power systems of the CEMA member nations will be strengthened after the 750 KV power transmission line between Zapadnoukrainskaya (USSR) and Al'bertirsha (Hungarian People's Republic) is placed in service. This line will provide for a significant increase in the export and intersystem exchange of electrical power between the USSR and the nations of the socialist camp.

With the connection of the Mongolian People's Republic power system via 220 KV power transmission line to the OES of Siberia, the power systems of the nations of the socialist community which operate in parallel, and based on which a unified power system for socialist nations will be created in the future, will encompass the territory from Ulan Bator in the east to Berlin in the west.

The coupling between the USSR power systems and the power system of Finland will be further strengthened through the construction of a rectifier and invertor substation (a DC "insert"), through which electrical power will be exported to Finland.

The structure of the power capacities brought on line during 1976-1980 in the USSR YeES will be governed by the following factors:

--The capacity of the electrical power stations will be formed primarily from large units with a unit capacity of 200, 300, 500 or 800 MW at thermal electrical power stations and 440 to 1,000 MW at AES's. During this period, it planned that three AES's with a power of 3 to 4 million KW each will be constructed, with the installation of thermal neutron reactors in them having a unit capacity of one million KW, as a result of which, the specific weight of AES's in the overall capacities brought on-line in the combined systems of the Tsentr and South will reach 40 percent, while the total AES capacity brought on line during 1976-1980 will amount 13.7 million KW. At five condensation GRES's, it is planned that the unit capacity of each of them will be brought up to 3 to 3.6 million KW.

During the 10th Five-Year Plan, the power systems will be supplemented with the first special flexible power sets, designed to cover the variable portion of the load schedule. For this purpose, a semi-peak steam turbine set with a capacity of 500 MW using gas-fuel oil at the Lukoml'skaya GRES and three gas turbine sets with a capacity of 100 MW each in the Moscow Power Administration will be placed in service. The Zagorskaya GAES with a capacity of 1,200 MW is being constructed with reversible sets having a capacity of 200 MW each in the generator mode.

In accordance with the volume of new electrical power station capacities brought on line, and for the purpose of assuring reliable electrical supply over the 10th Five-Year Plan, the overall length of 35 KV and higher electrical power transmission lines should increase by approximately 140,000 km (see Table 6.5).

A special characteristic feature of the development of electrical power networks in the 10th Five-Year Plan is the construction of about 10,000 km of electrical power transmission lines at a voltage of 500 KV and higher.

The construction of the following extremely important intersystem links number amoung the largest projects to develop the main electrical power network of the USSR YeES in the 10th Five-Year Plan: the 750 KV line from the Smolenskaya and Kurskaya AES's to the Mscow and Dneprovskaya power system; the 750 KV line from the Chernobyl'skaya AES to the Western Ukraine; the 500 KV intersystem trunk line between Siberia-Kazakhstan-Urals; and the Transcaucasus--Northern Caucasus--Donbass 500 KV trunk transmission line.

The boundaries of the nation's Unified Power System will be expanded beyond the 1980 limits through the connection of the Central Asia OES based on the expansion of the 500 KV networks, as well as the connection of the East OES using 220 to 500 KV networks, being constructed for the electrification of the Baykal-Amur trunk line and being created in its zone of industrial facilities.

The USSR Unified Power System encompasses almost all of the inhabited territory of the nation and concentrates practically all of the nationwide generation of electrical power.

The development of power engineering in the USSR will subsequently take place under conditions where the increase in the demand for fuel for electrical power stations will be met primarily by nuclear fuel, the coals of the eastern regions, as well as gas from Tyumen' deposits.

Because of this, practically all of the increase in power capacities in the European zone of the USSR YeES after 1980 will be accomplished through the introduction of large nuclear electrical power stations with a unit capacity of 6 million KW and more, including nuclear TETs's. The structure of the capacities in the European area will change by virtue of the introduction of flexible installations: steam turbine, gas turbine and water storage electrical power stations to cover the peak portion of the load schedule, as well as TETs's to provide the heat supply.

According to calculations, it will be necessary to bring on-line the capacities of flexible electrical power stations in an amount of no less than 20 percent of the overall power capacities being brought on-line.

The wide scale utilization of the coals of the eastern regions should take place through the construction of two power facilities based on the construction of large condensation electrical power stations with a unit capacity of 4 million KW (8 x 500) and 6.4 million KW (8 x 800) respectively at the base for the Ekibastuz and Kansko-Achinsk coal basins, as well as the ultrahigh voltage power transmission system with a large carrying capacity running from them to the Urals and to the European regions of the nation. The first sets at the GRES of the Ekibastuz power complex will be brought on line as early as the 10th Five-Year Plan.

To assure the overall stability and operational efficiency of the integrated power systems incorporated in the YeES and strengthen the ties to the power systems of CEMA member nations, it is necessary to create an expanded 750 KV network in the nation's western regions and to bring on line 1,150 KV AC intersystem transits as well as high power transport trunks at voltages of 1,500 and 2,250 KV DC to transmit electrical power to the nation's center from the Ekibastuz and Kansko-Achinsk power complexes, as well as to boost the overall operational stability of the association of Tsentr, Siberia and Central Asia power systems.

The engineering plan for the Ekibastuz--Tsentr 1,500 KV direct current transmission line was approved in 1977, the equipment for it was developed, a high power test stand was constructed in Toliatti, and the construction of a similar test stand at the Belyy Rast substation near Moscow is being completed; the Energoset'proyekt Institute is working up a technical and economic report on a 2,250 KV direct current power transmission line with a transmitting capacity of 13.5 million KW from Itat to the European area of the nation.

The strengthening of the weakest sections of the main network of the YeES is the most effective measure for assuring the full utilization of existing power capacities, as well as increasing the operational stability of power associations and the reliability of the power supply.

The 1,150 KV alternating current trunk line is of paramount importance in strengthening the tie between the integrated power systems of Siberia, Kazakhstan, and the Urals. The construction of the first section of this transit line, the experimental industrial Itat-Novokuznetsk 1,150 KV power transmission line, is planned before 1980.

The organization of parallel operation of the USSR YeES with the power systems of CEMA member nations is related to the increase in the electrical power exported to these nations. The meeting of obligations by the USSR at the new stage of integration in power engineering of the socialist nations requires the acceleration of the implementation of a whole set of measures to provide for a stable power balance in the South OES and the design of a reliable control system for parallel operation of the power system. An important place is assigned to the Rovenskaya AES in the solution of this problem; it is planned that the first 440 MW power units will be placed in service here in the 10th Five-Year Plan, as well as at the Yuzhno-Ukrainskaya AES.

The conditions for the external connections of the USSR YeES to the power systems of the CEMA member nations exert a significant influence on the operation of all of the major internal transit lines of the USSR Unified Power System, which are separated by several thousand kilometers.

Under these conditions, it is necessary to accelerate the creation of comprehensive frequency and power control systems as well as counter-emergency automation to assure stable operation of all sections of the USSR YeES and export electrical power to CEMA member nations.

In summing up the analysis of the problems of the development of power engineering systems for the future, one can argue that in the next 10 to 15 years, substantial changes will take place in the power engineering of the Soviet Union.

All OES's, with the exception of the Kamchatka and Magadan power systems, will be integrated into the USSR Unified Power System during this period of time. As a result of combining the power systems, according to the calculations of the Energoset'proyekt Institute, the installed (standby) capacity can be reduced by approximately 35 million KW because of the fact that the load maxima do not coincide.

The construction of high power AC and DC power transmission lines will provide for the transmission of large masses of power from the eastern regions to the nation's center.

Direct current lines make it possible to increase the dynamic and static stability of the integrated power systems.

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